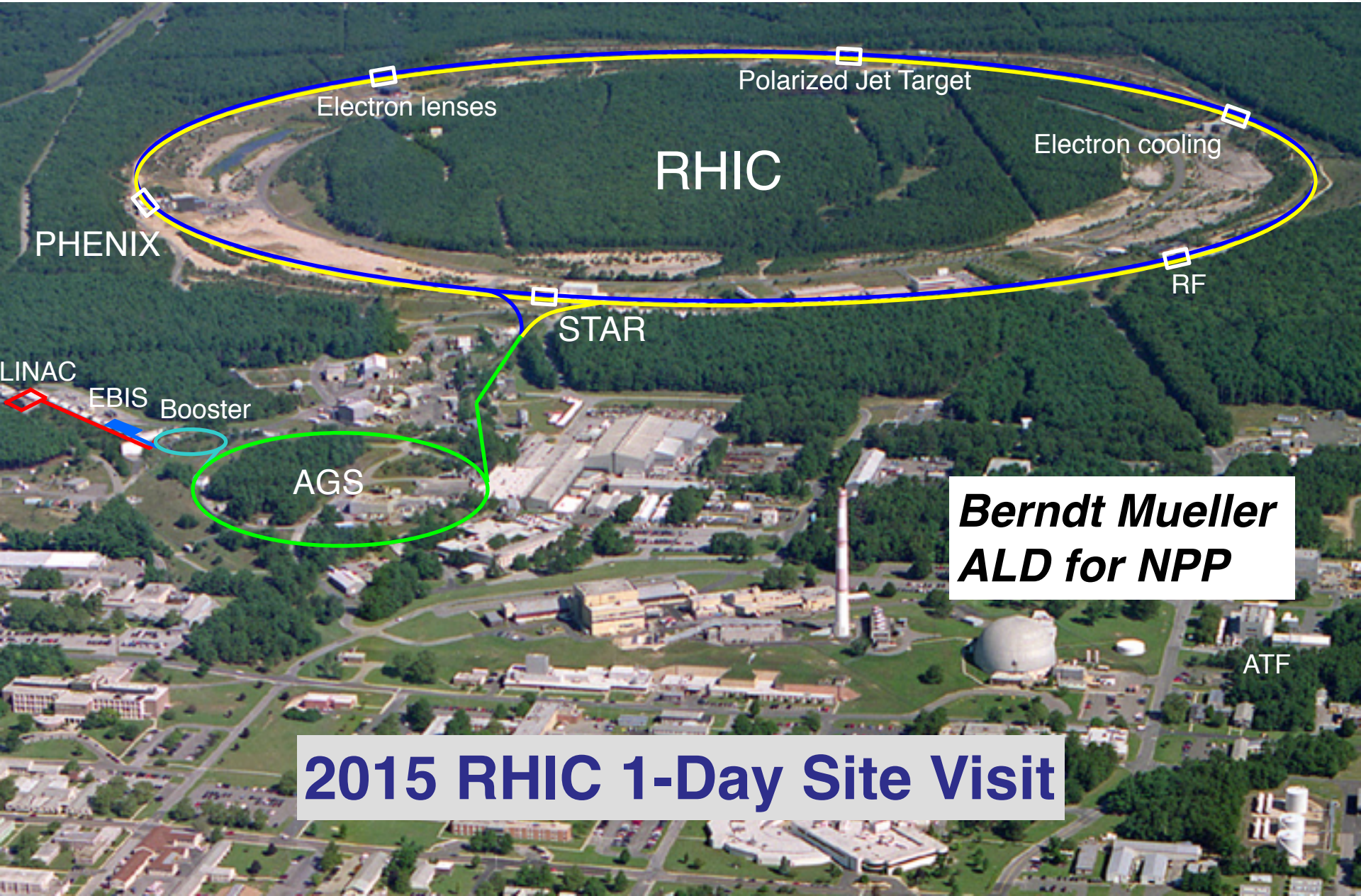
RHIC S&T Overview



Berndt Mueller
ALD for NPP

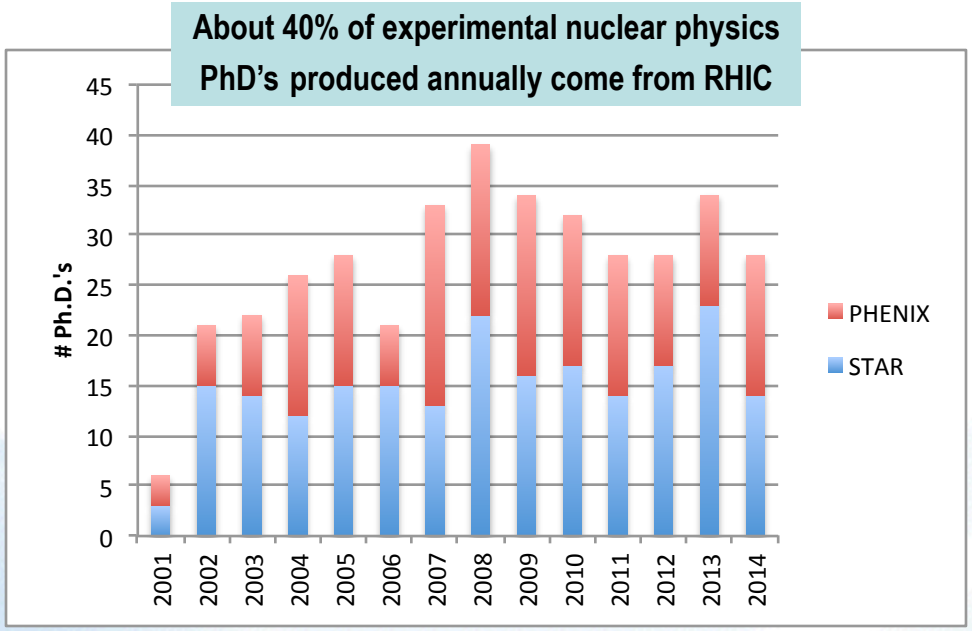
2015 RHIC 1-Day Site Visit

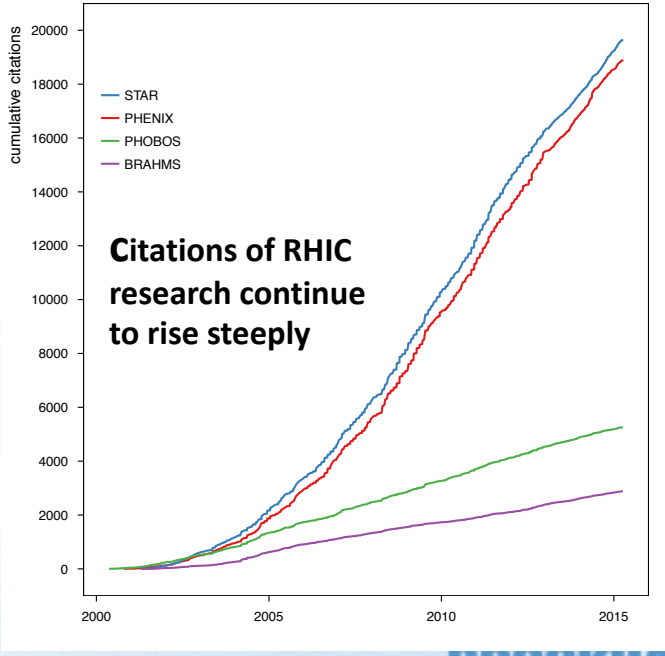
Agenda

- RHIC Status and overview of RHIC Run 15
- Plans for RHIC Run 16 and 17
- Recent science highlights
- Longer-range science and facility upgrade goals
- Collaboration management
- Budget issues

RHIC: Productivity and Impact

Collaboration	Total # Refereed Papers	Total # Citations for Ref'd Papers	# PRL's	# Citations for 2005 White Paper	Position Among Most Cited NP Papers 2001-14	# Papers with >250 Citations
PHENIX	142	18,812	66	1,923	4	17
STAR	171	19,673	65	2,008	3	19
PHOBOS	39	4,999	15	1,488	5	1
BRAHMS	22	3,477	10	1,462	6	3
Total	**374**	**46,961**	**156**	**5,943**	**4 in top 10**	**40**





RHIC related awards (2015)

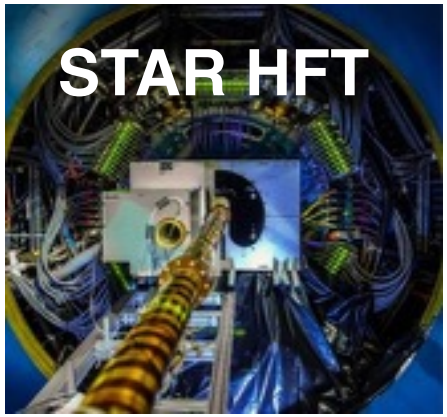
- Ernest O. Lawrence Award:
  - Mei Bai
- APS Bonner Prize:
  - M. Gyulassy & H. Wieman
- APS Feshbach Prize:
  - L. McLerran
- BNL S&T Award:
  - Flemming Videbaek
- ATLAS Thesis Award
  - Dennis Perepelitsa
- Excellence Professor (U Heidelberg)
  - Raju Venugopalan

Mei Bai

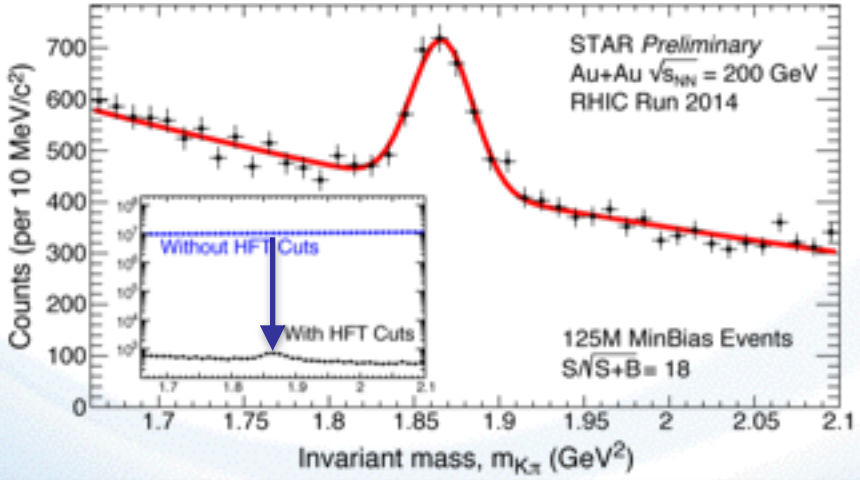
Presented today at DOE HQ

RHIC: Recent Detector Upgrades

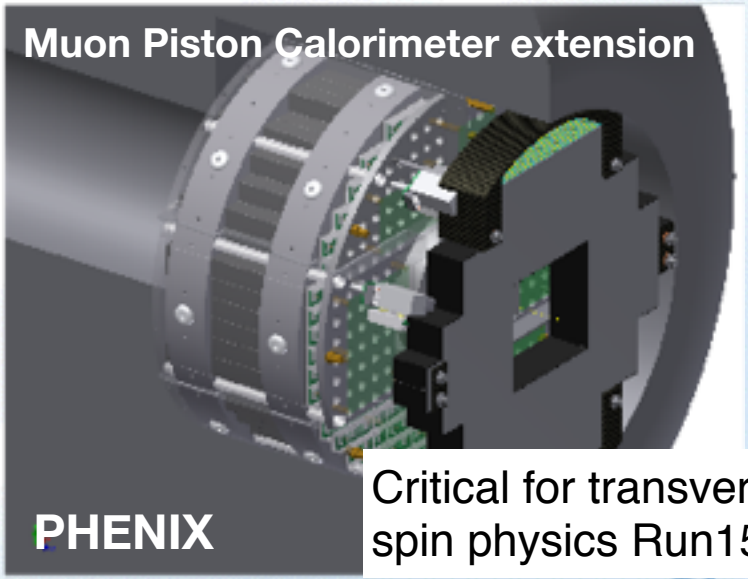
Fully reconstruct open charm/beauty hadrons with displaced vertex



Completed on schedule and below cost

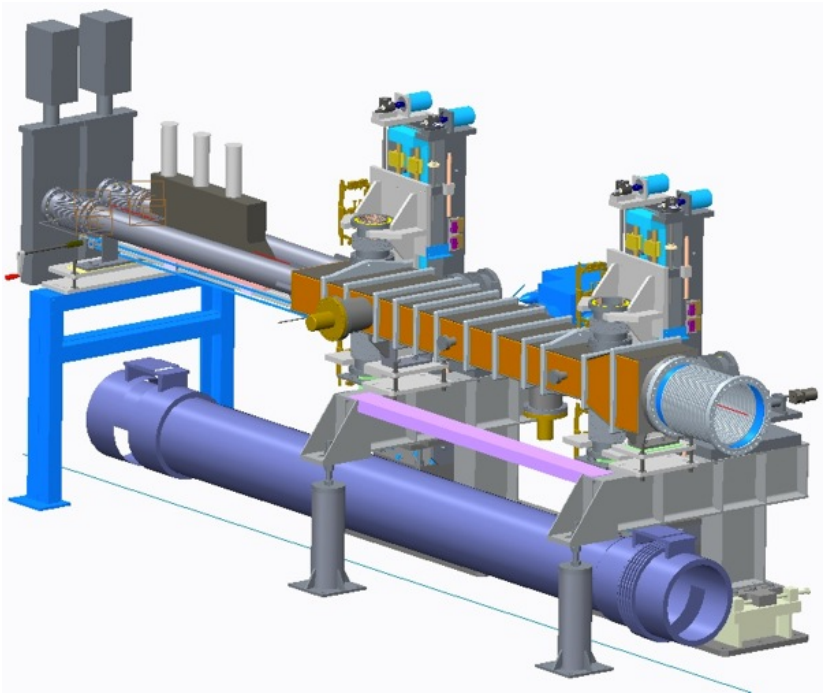


Enhances triggering capabilities for heavy quarkonia



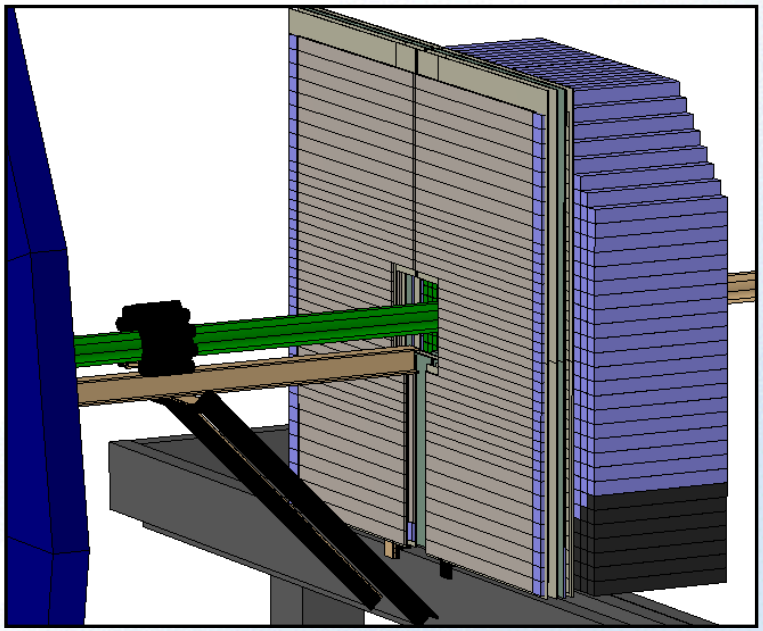
Critical for transverse spin physics Run15

Small STAR upgrades



Roman Pots tag diffractive protons

Forward Meson Spectrometer with Pre-shower Detector

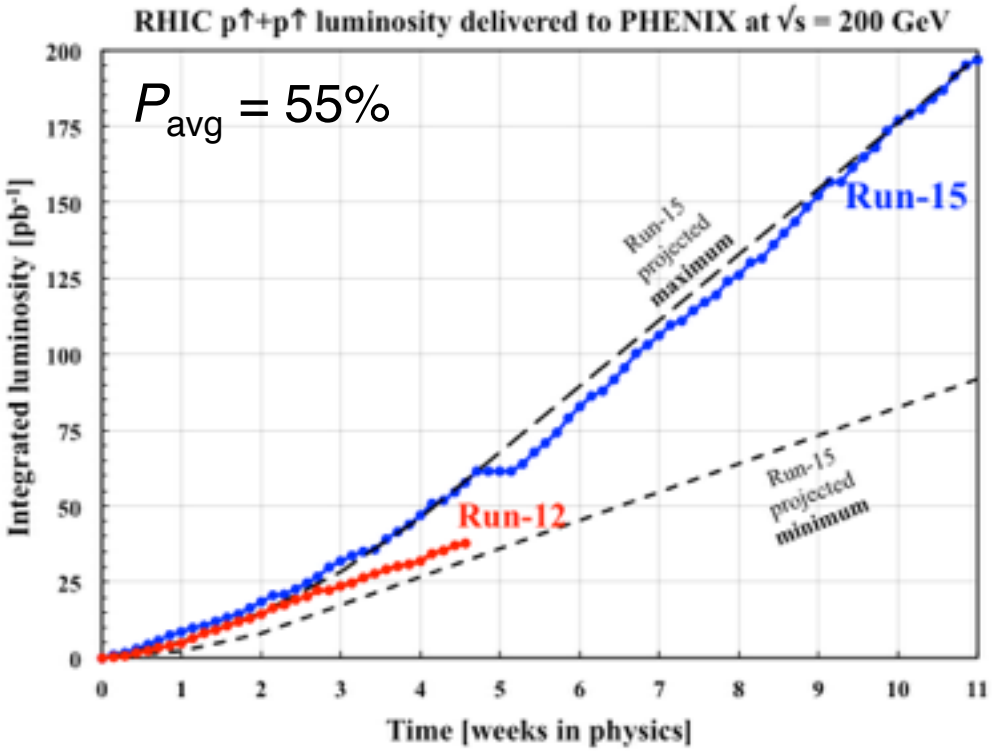


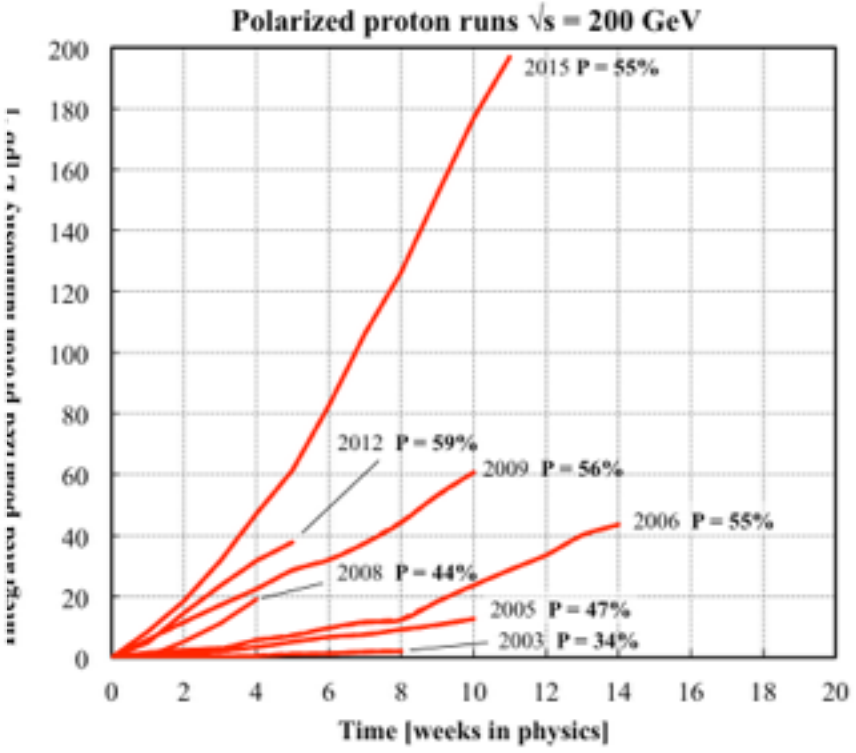
RHIC sets new records …

Run-15 p↑+p↑ at $\sqrt{s}$ = 200 GeV

L = 25 pb^{-1}/week **(2.7× 2012)**

Run-15 integrated luminosity at $\sqrt{s}$ = 200 GeV exceeds sum of all previous runs

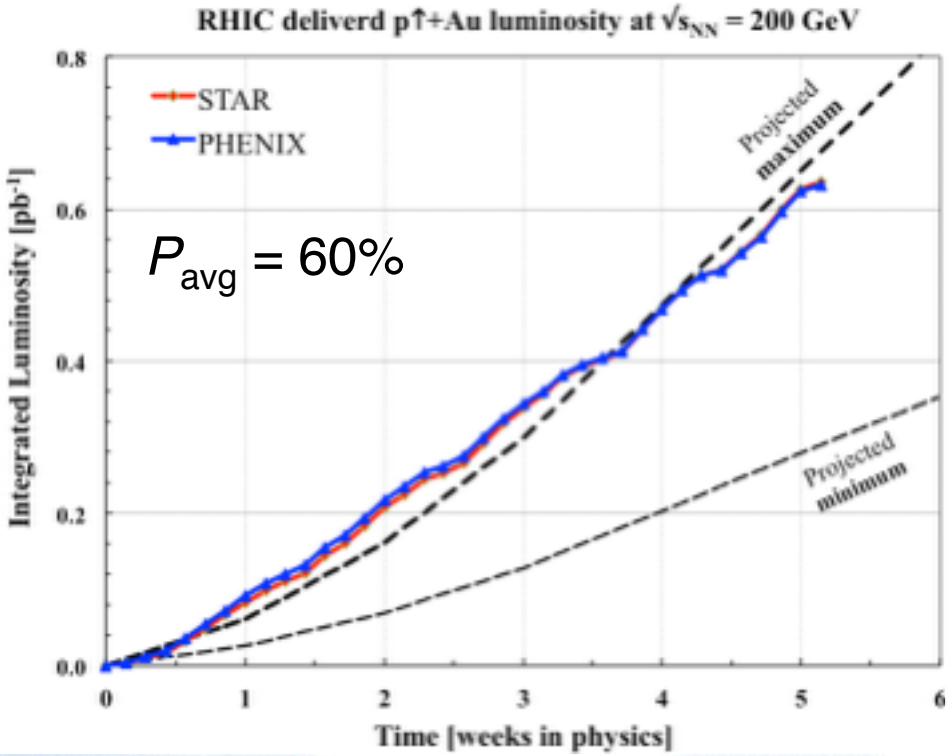


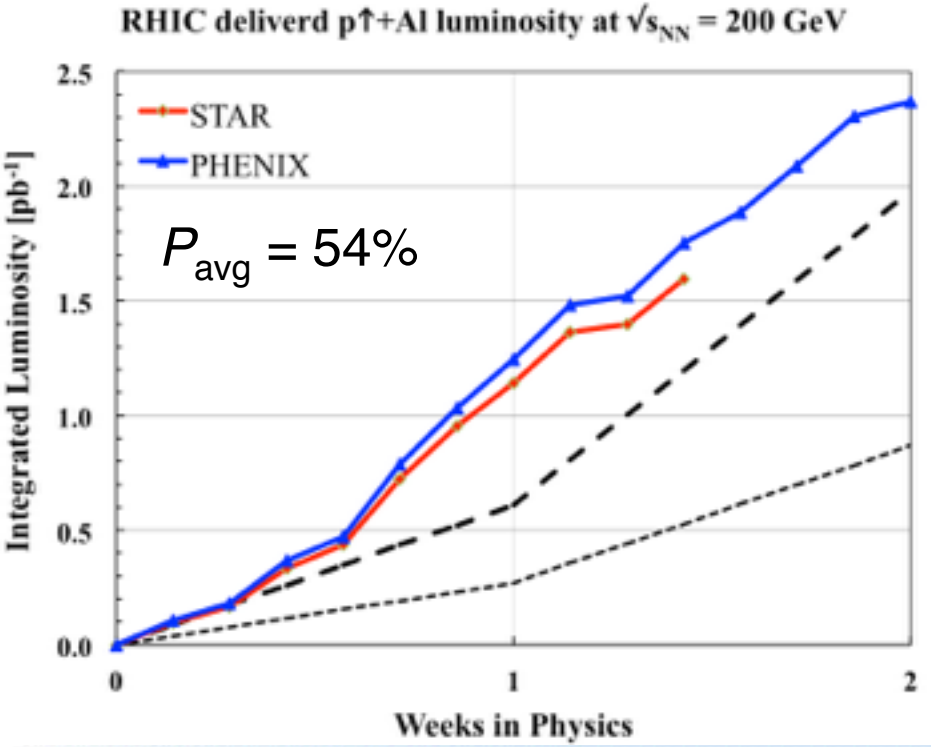


… and shows its versatility

Run-15 p↑+Au and p↑+Al at $\sqrt{s}$ = 200 GeV

2 new (asymmetric) operating modes – met or exceeded luminosity goals





Run 16 & 17 plans

PAC recommendations (in order of priority):

Run-16

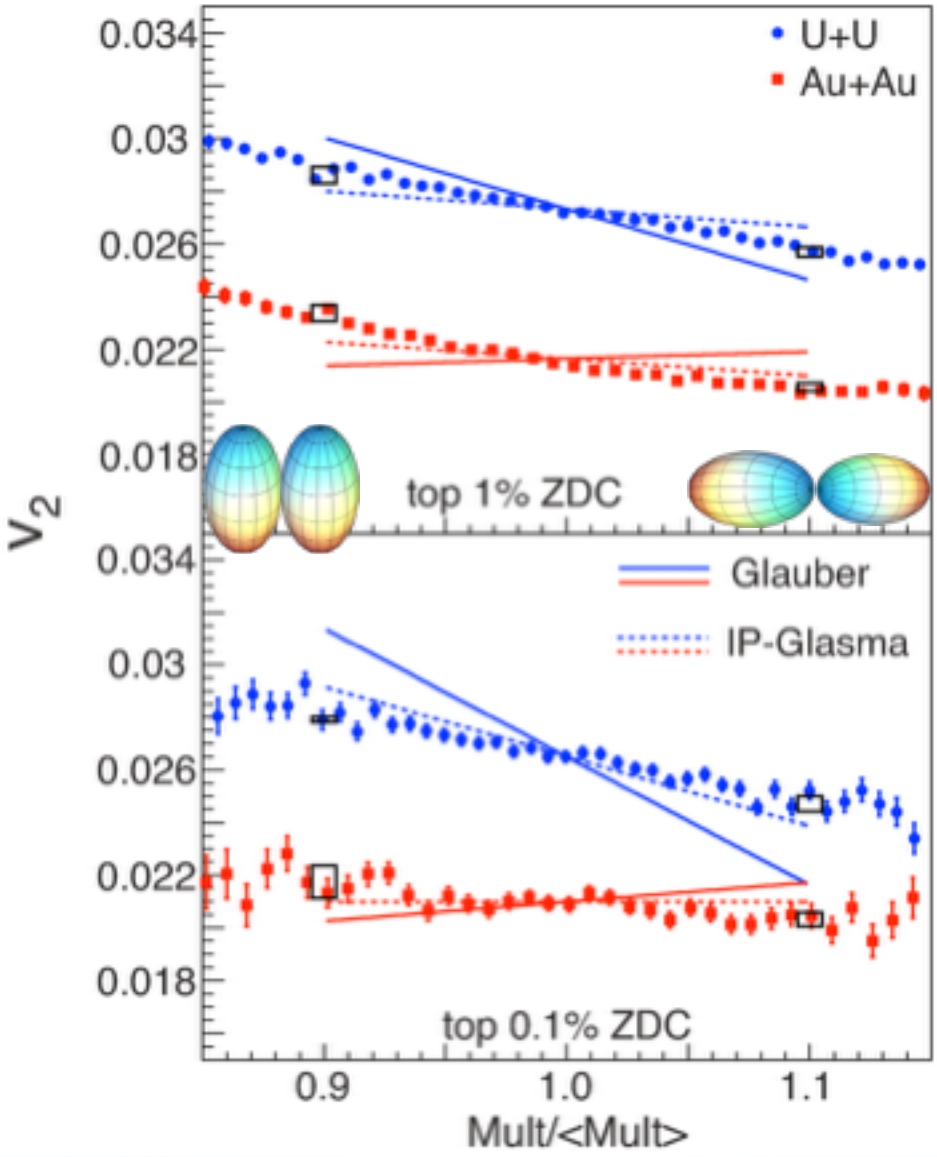
- Au+Au at 100 GeV, 10 weeks
  56 MHz SRF, further increase in bunch intensity
- Au+p↑ (or p↑+Au or d+Au) at 100, 31.2, 20, 10 GeV/nucleon, 5 weeks
  PHENIX / STAR protection, task force set up
- p↑+p↑ at 31.2 GeV, 2 weeks
- Au+Au at 31.2 GeV, up to 4 weeks

Run-17

- p↑+p↑ at 255 GeV, ≥ 11 weeks
- Ru+Ru and Zr+Zr (A = 96 in both cases)
- p↑+p↑ at energies matching p+Au (d+Au) energy scan

Science Highlights

Shape Matters: U+U Collisions

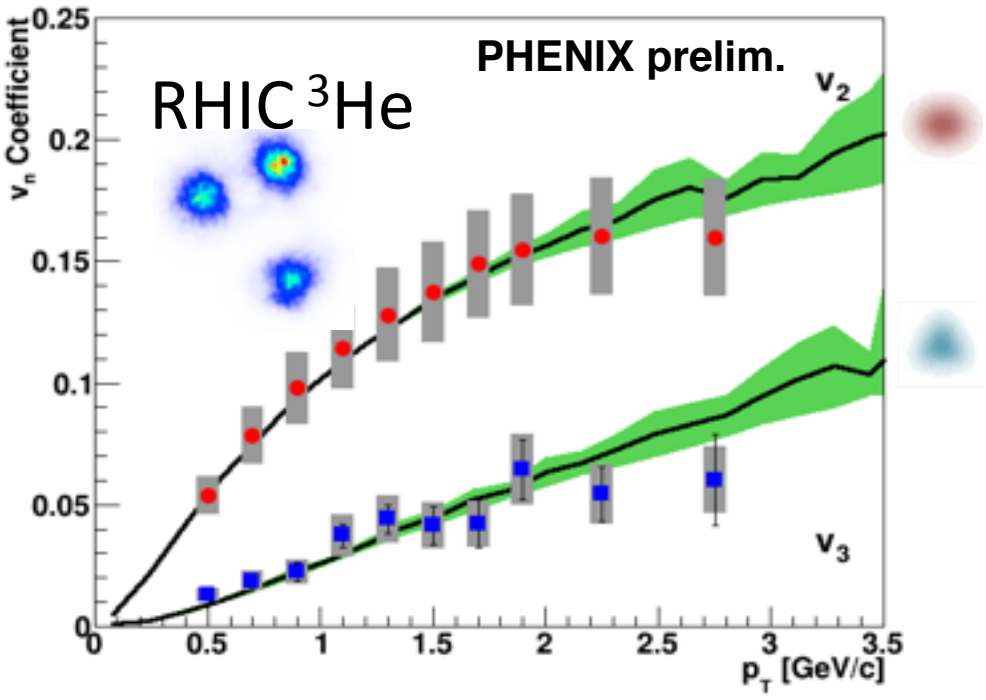


STAR Collaboration
arXiv:1505.07812

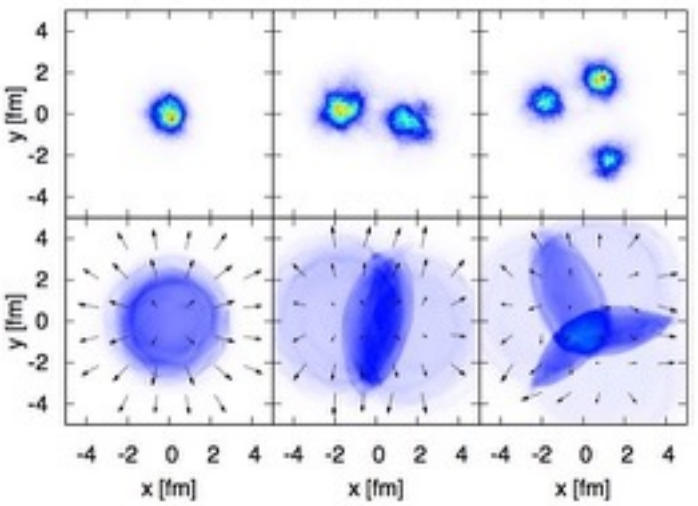
IP-Glasma model, but not NN Glauber model, consistent with observations.

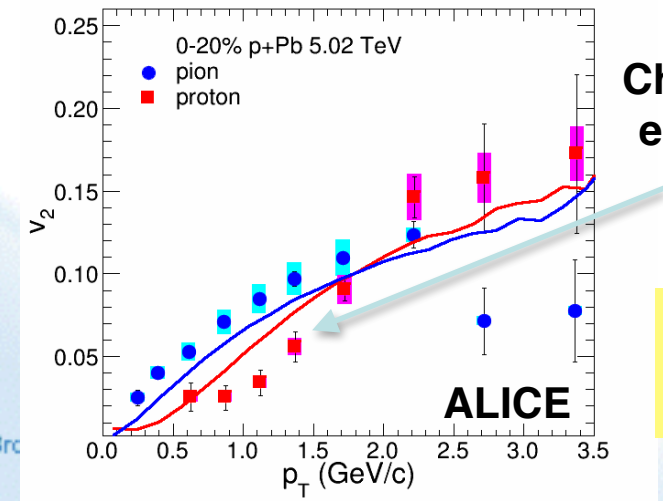
→ **Initial state fluctuations occur at the parton level**

How small can a QGP droplet be?

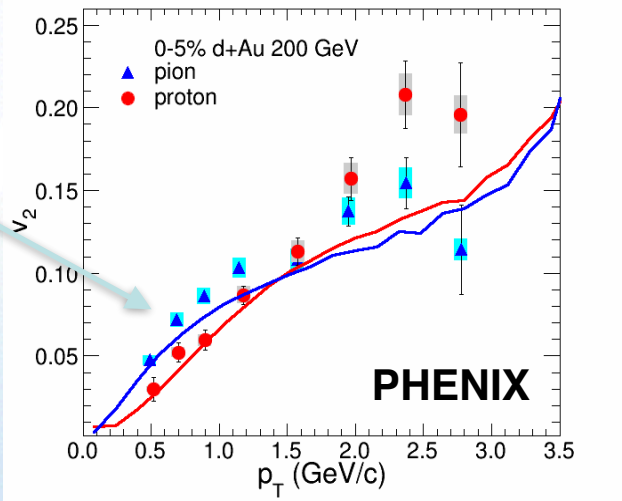


Very successful 3-week run resulted in 2.2 billion recorded minimum bias ^{3}He+Au collisions (PHENIX)





Characteristic differential elliptic flow for hadrons of different mass

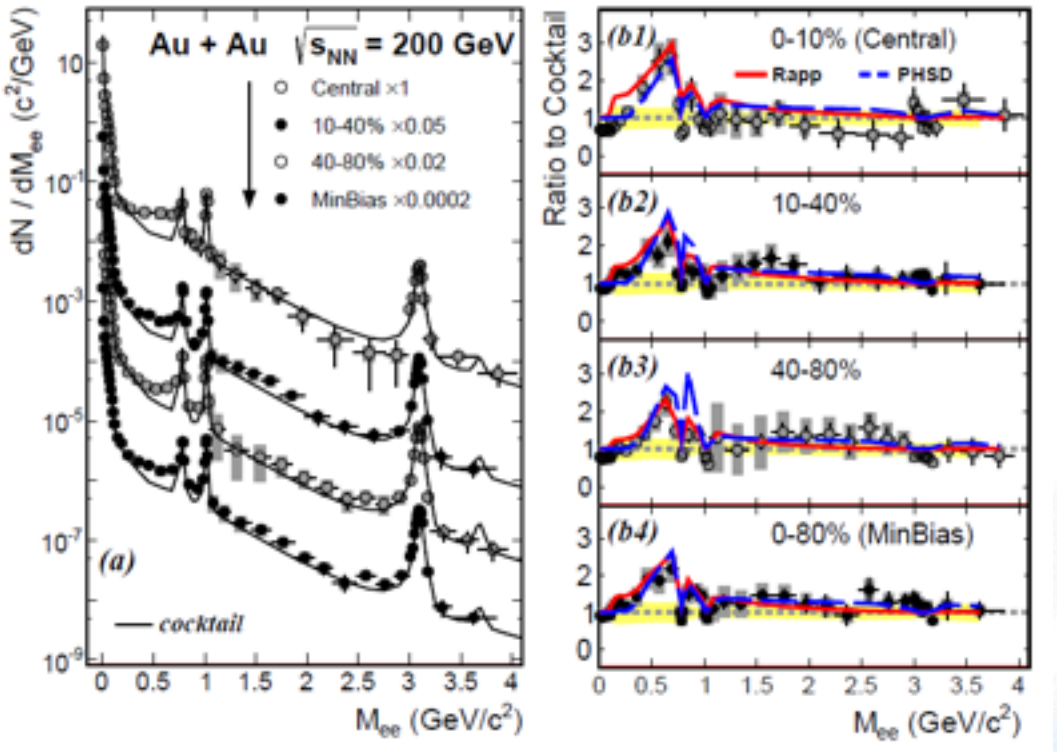


p+Au run will be a critical test

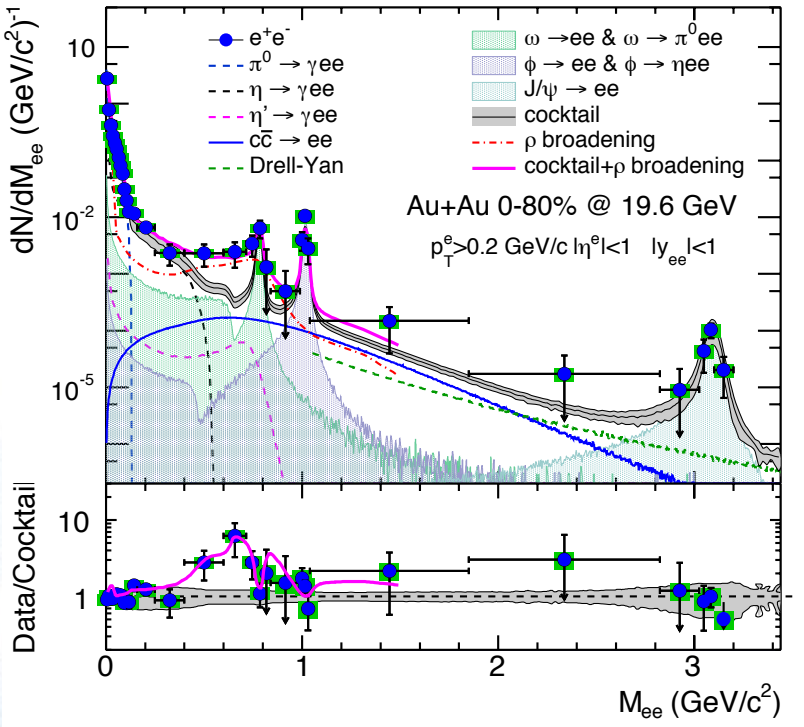
Chiral Symmetry Restoration

Significant excess is observed in 0.3<M_{ee}<0.8 GeV/c^2, representing the hot, dense medium contribution; described by a broadened ρ spectra function. Mapping the temperature and baryon-density dependence toward Chiral Symmetry Restoration (BES II goals)

Phys. Rev. Lett. 113 (2014) 22301
arXiv: 1504.01317, submitted to PRC



arXiv:1501.05341, submitted to PLB



Chiral Magnetic wave

Editors' Suggestion

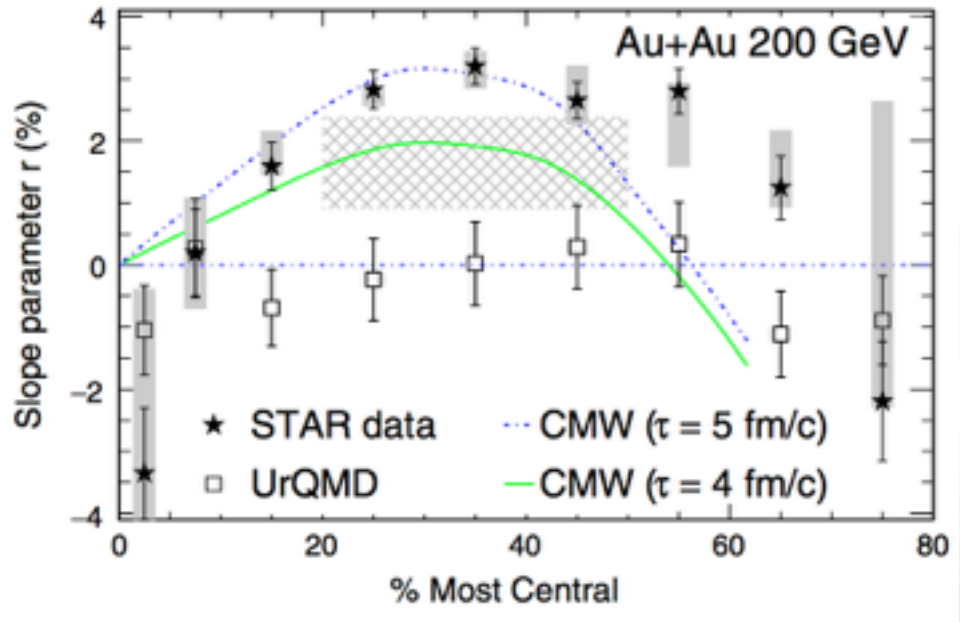
Observation of Charge Asymmetry Dependence of Pion Elliptic Flow and the Possible Chiral Magnetic Wave in Heavy-Ion Collisions

L. Adamczyk *et al.* (STAR Collaboration)

Phys. Rev. Lett. **114**, 252302 (2015) – Published 26 June 2015

A possible signature of chiral symmetry restoration, in the form of a chiral magnetic wave in the quark-gluon plasma, has been observed in heavy-ion collisions at RHIC.

Show Abstract +

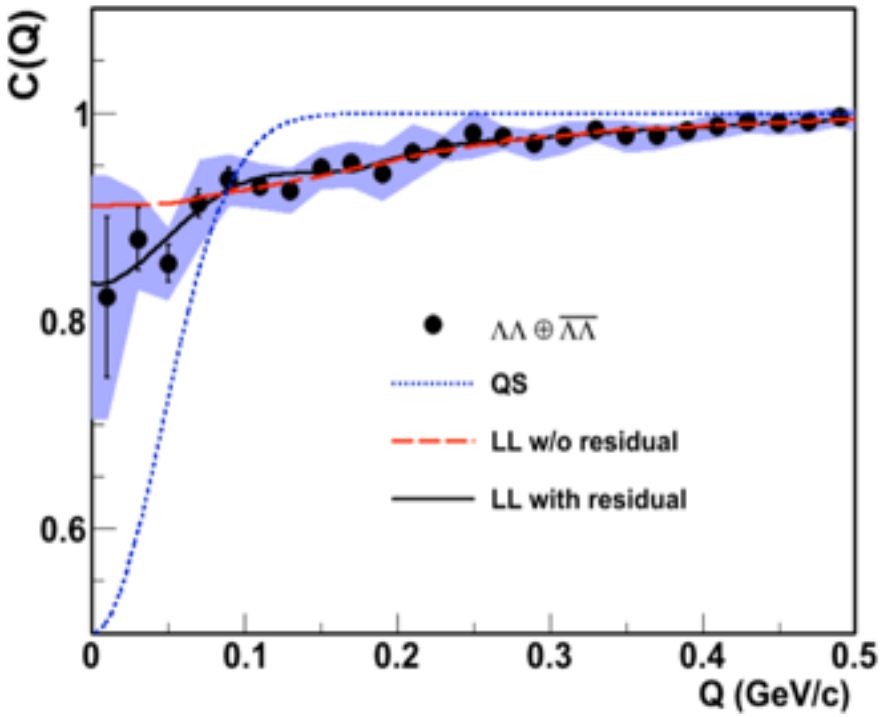


- STAR has published a few papers on possible Chiral Magnetic Effect and potential background
- Implication beyond our field

Continue research:

- U+U collisions
- BES I results on CME
- BES II with more statistics
- Chiral Magnetic Wave
- Chiral Vortical Effect

Baryon-baryon interactions

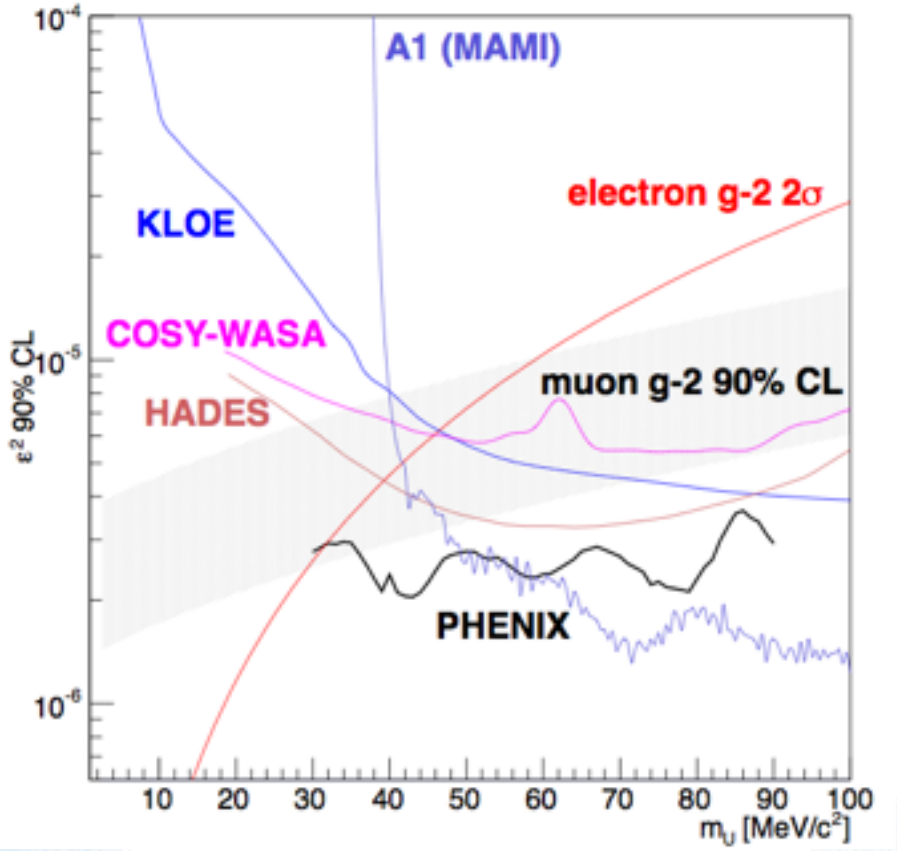


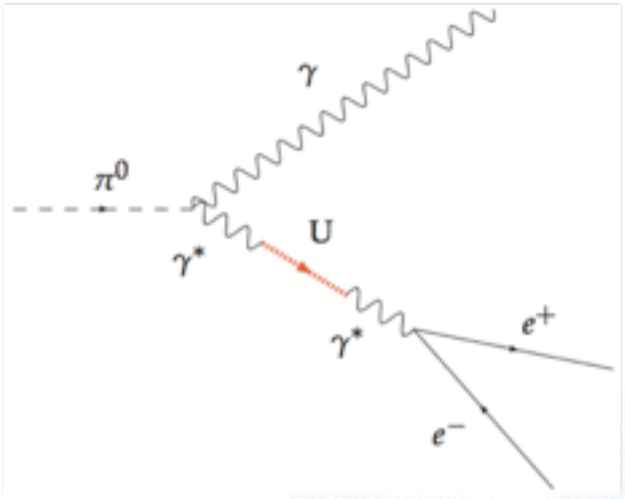
- Use RHIC as a hyperon factory to investigate hyperon-hyperon interactions.
- Input to baryon-baryon interaction models and study of the equation of state for neutron stars.
- The ΛΛ interaction is also closely related to the existence of the H dibaryon postulated in.

Antimatter hypertriton, Science 328 (2010) 58
Antimatter Hellium-4, Nature 473 (2011) 353
ΛΛ Correlation Function, PRL 114 (2015)022301
Antimatter nucleon interactions, to be submitted
Antimatter muonic atoms, STAR Preliminary
Glueball Search tagged by Roman Pots, run15

Dark photons?

Phys. Rev. D91 (2015) 031901

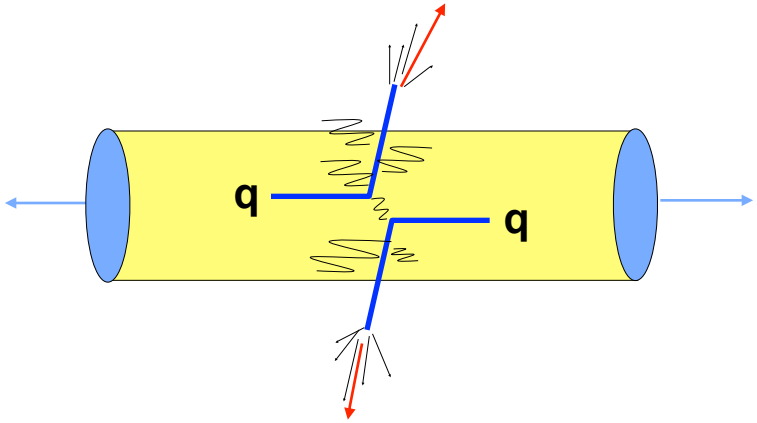




PHENIX: excellent electron ID and e^+e^- mass resolution – huge sample of π^0 Dalitz decays

Recent combined limits – WASA, HADES, A1, BaBar, PHENIX, NA62 – rule out essentially all parameter space for the minimal version of a dark photon explaining the $(g-2)_\mu$ anomaly

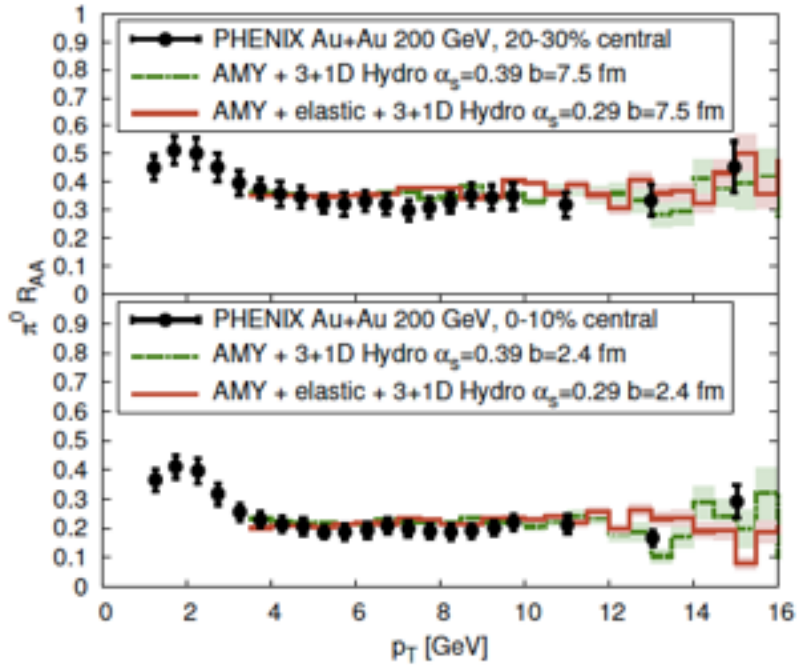
Jet quenching



Toward quantitative measurement of basic medium properties: *q-hat*

$$\frac{dE}{dx} = -C_2 \alpha_s \hat{q} L \qquad \frac{dE}{dx} = -C_2 \hat{e}$$

Radiative Collisional



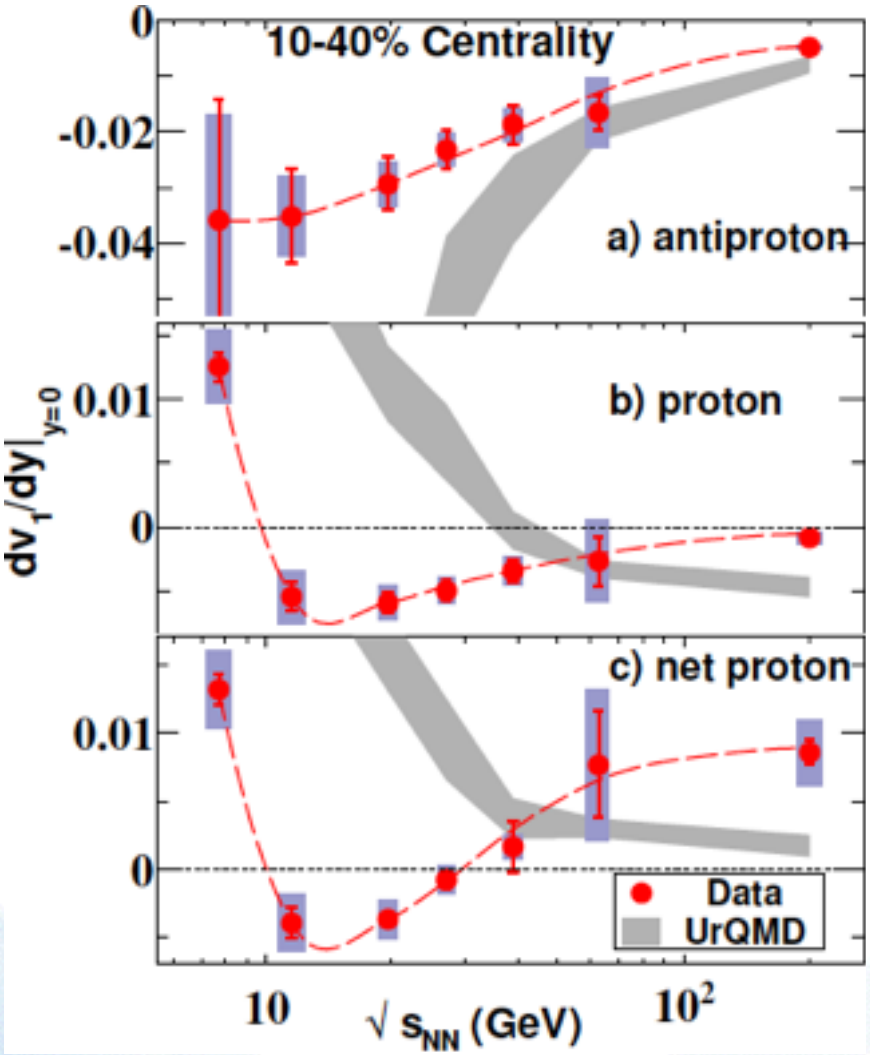
JET Collaboration

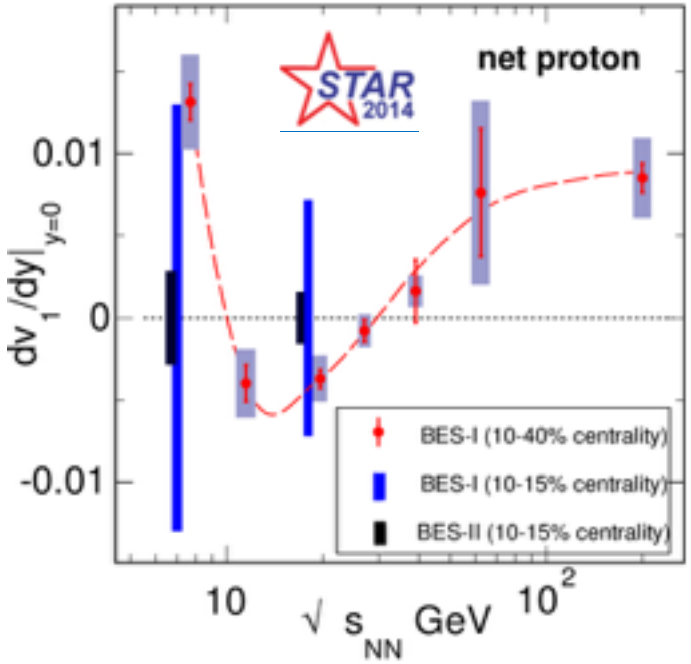
$$\frac{\hat{q}}{T^3} = \begin{cases} 4.6 \pm 1.2 & \text{at RHIC} \\ 3.7 \pm 1.4 & \text{at LHC} \end{cases}$$

Phys. Rev. C 90 (2014) 014909

Topical collaboration concept proves its merits

Softening of the Equation of State: v_1

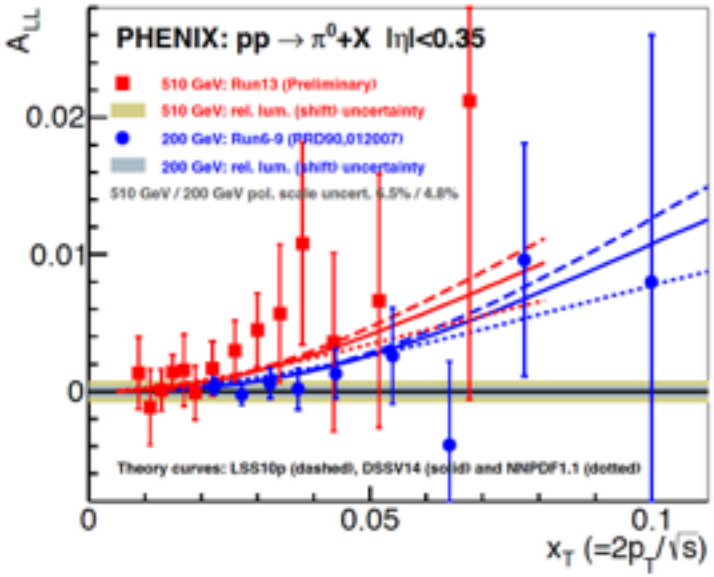


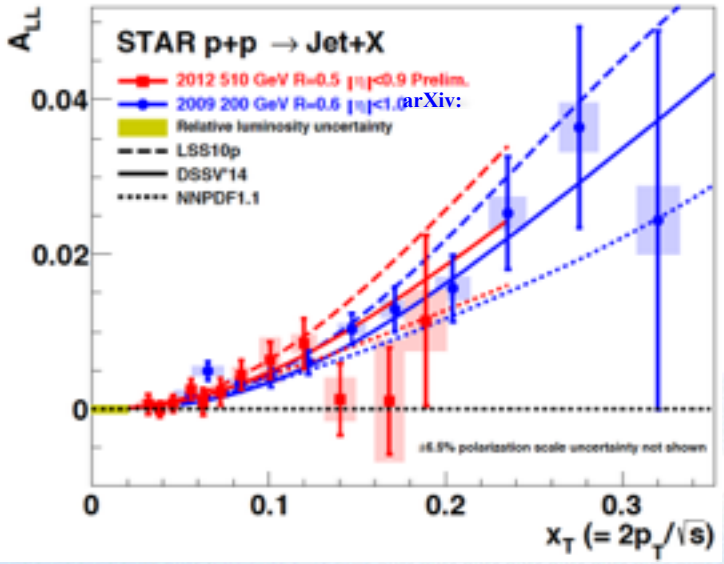


- **Minimum in v_1 indicates a softening equation of state in the transition region of the phase diagram.**
- Precision measurement requires BES-II data allowing dv_1/dy to be measured with tightly specified centrality.

Phys. Rev. Lett, 112 (2014) 162301

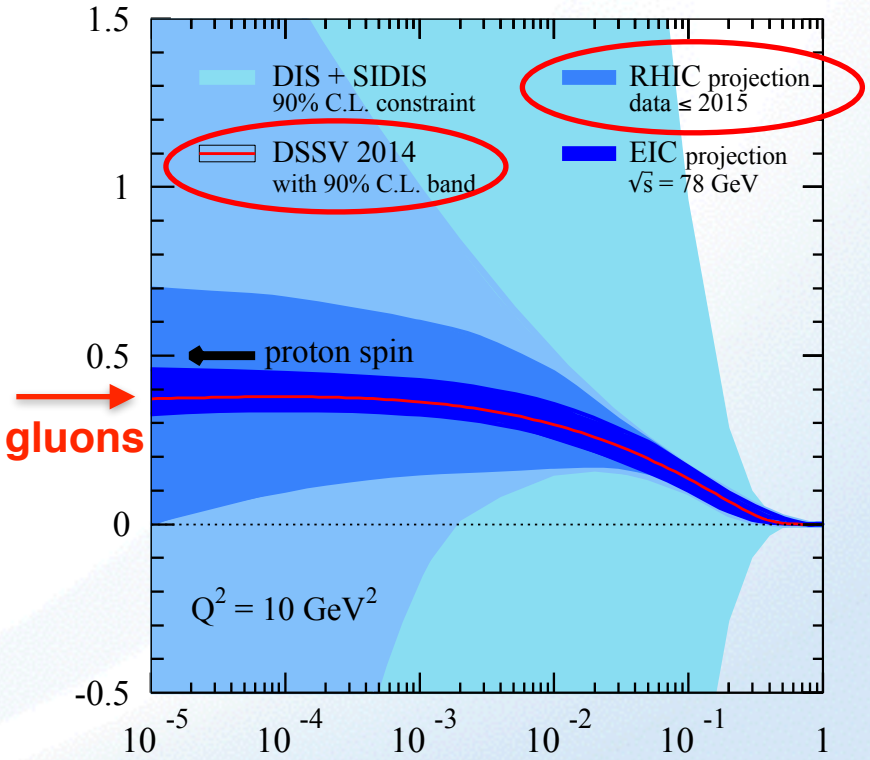
Δg from π^0 and jets @ RHIC





$$\int_{0.05}^{1.0} dx\Delta g \sim 0.2 \pm^{0.06}_{0.07} @\ 10\ \mathrm{GeV}^2$$

Gluons may contribute 70% of the proton spin



BROOKHAVEN NATIONAL LABORATORY

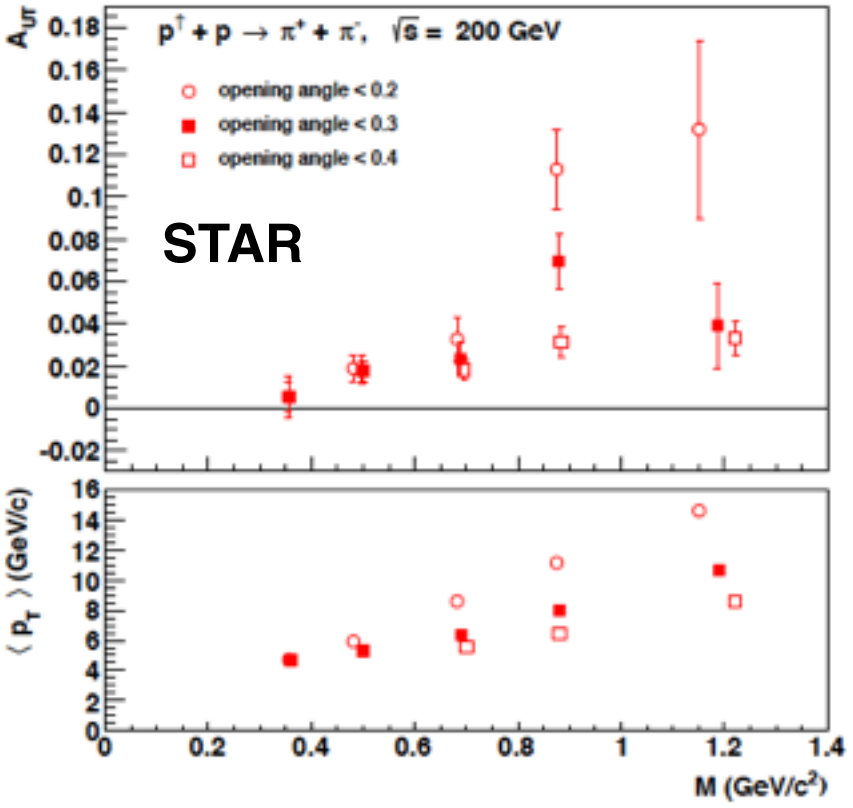
Transverse spin structure of the proton

Transverse single spin asymmetries (TSSA) give access to transversity δq_f

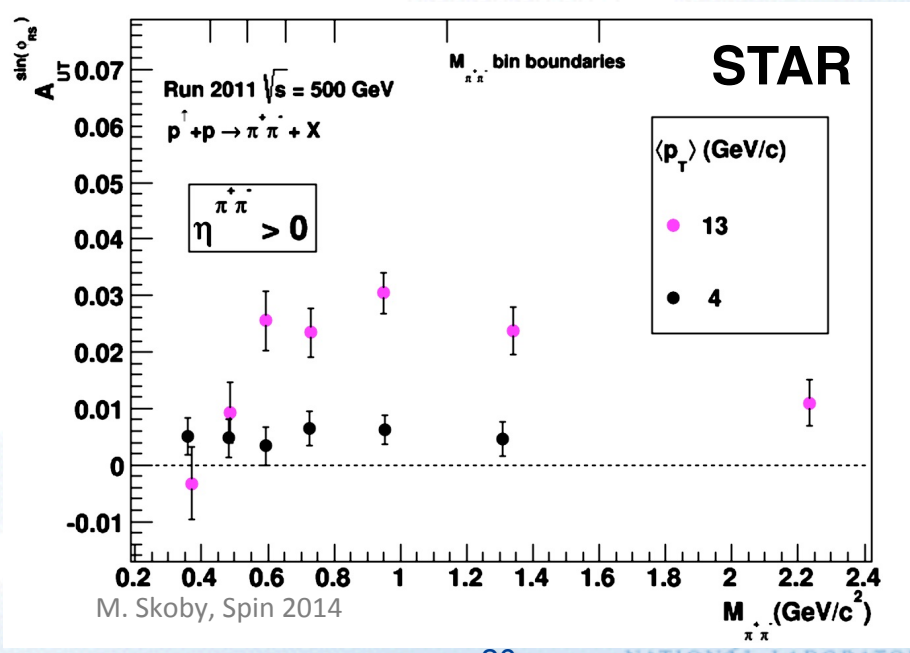
→ critical together with q_f and Δq_f for a complete description of the proton wave function

$p\uparrow + p \rightarrow \pi^+\pi^- + X$ transversity x new spin-dependent FF (interference FF)

arXiv:1504.00415 → submitted to PRL



- first significant non zero TSSA at mid-rapidity at √s=200GeV & √s=500GeV
- A_{UT} increasing with p_T



M. Skoby, Spin 2014

Future Science 2015-22

A whirlwind tour

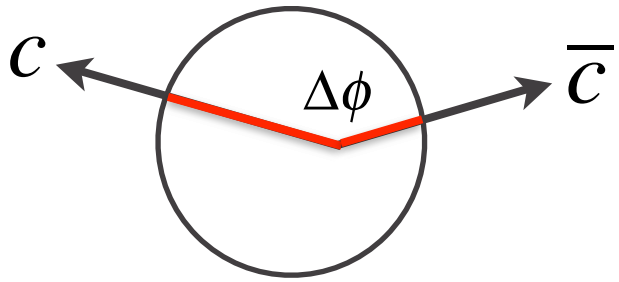
New Questions

- Do the initial conditions for the hydrodynamic expansion contain unambiguous information about saturated gluon fields in nuclei?
- What is the smallest collision system that behaves collectively?
- What does the QCD phase diagram look like? Does it contain a critical point in the HG-QGP transition region? Does the HG-QGP transition become a first-order phase transition for large μ_B?
- What is the structure of the strongly coupled QGP at varying length scales? What makes it a liquid?
- What do Upsilon states tell us about quark deconfinement and hadronization?
- What do transversely polarized protons tell us about the coupled spin-momentum dynamics of QCD at different scales?

Heavy quarks probes

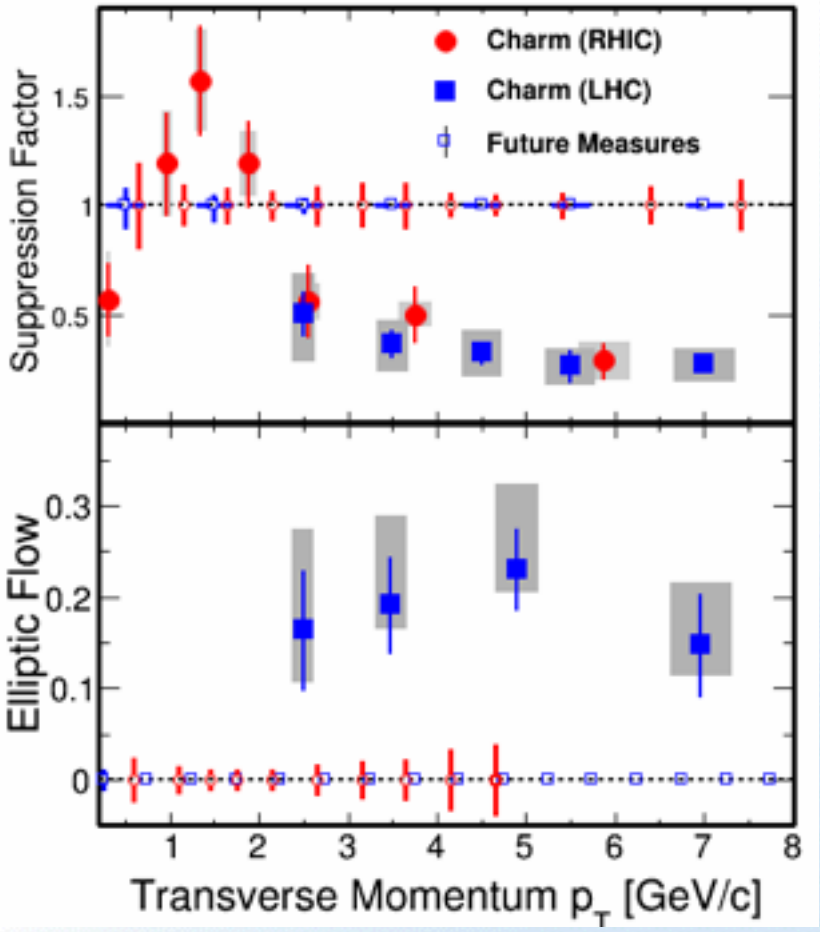
Suppression of mesons carrying open heavy flavor = energy loss of heavy quarks (*c, b*) explores mechanism of energy loss via medium color response.

Spectrum of heavy quarks is important for predicting c-cbar recombination.



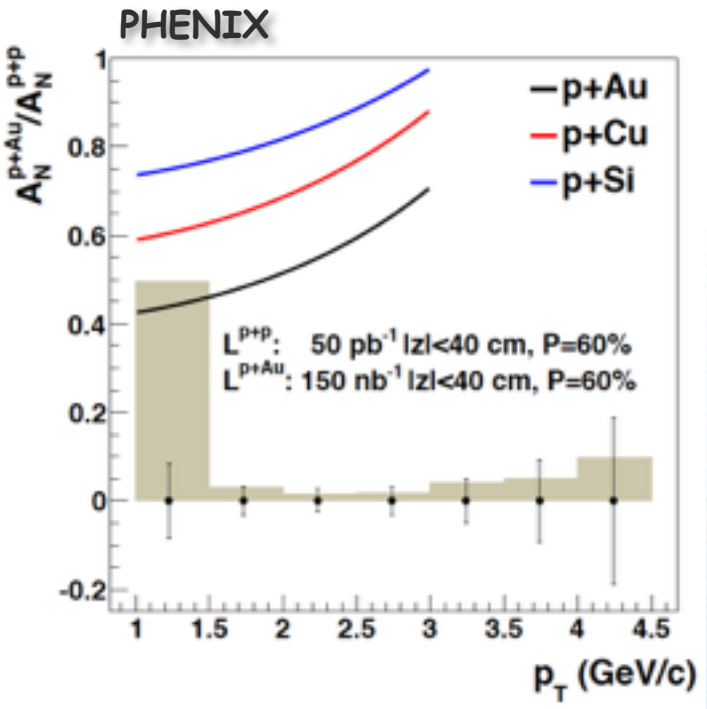
Different mass quarks permit to distinguish different energy loss scenarios

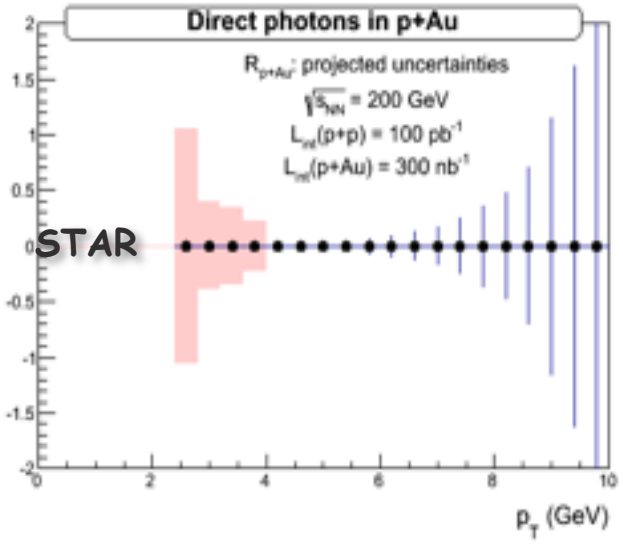
Charm R_{AA} and elliptic flow



Initial conditions for A+A collisions

- unique RHIC capability: $p^{\uparrow}A$
- Synergy between *CGC* based theory and transverse spin physics
- Is A_N suppressed with increasing A?
  → first results run-15





Direct photon measurements can help separate strong interactions in entrance and exit channel in p+A collisions

R_{pA} at 3<η <4: access to low x (10^{-4} – 10^{-5}): First results from Run-15

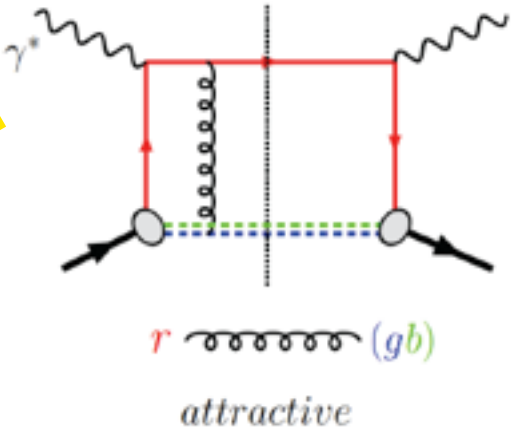
Transverse polarized p+p collisions

Access the dynamic structure of protons:

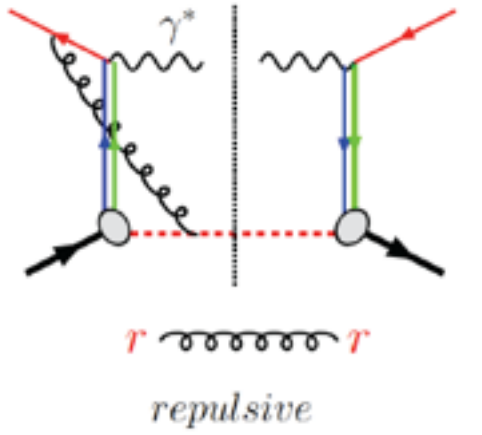
→ **Test and confirm QCD structure of color spin interactions**
- → **Non-universality of transverse momentum dependent functions**
- → **$Sivers_{DIS} = -Sivers_{pp}$**
  - → **Observable: A_N for Drell-Yan and $W^{+/-}$ production**

Achieves NP Performance Milestone HP13 in Run 17?

DIS:
γq-scattering attractive



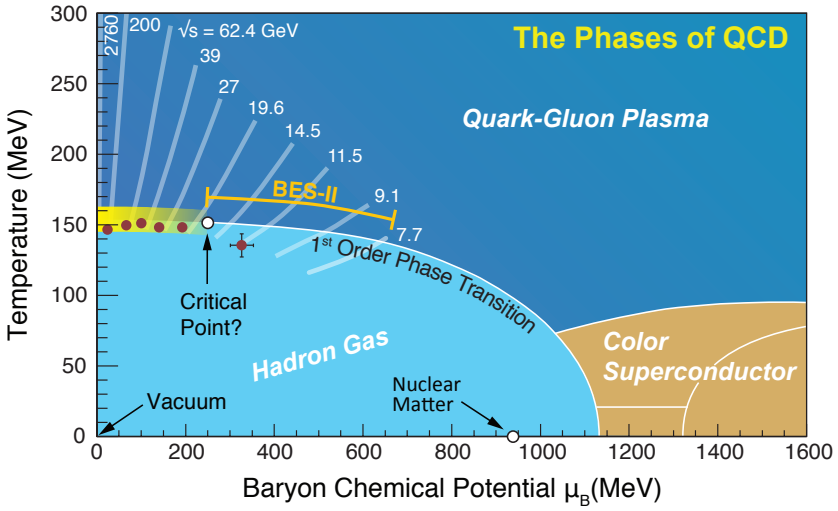
pp:
qqbar-anhilation repulsive



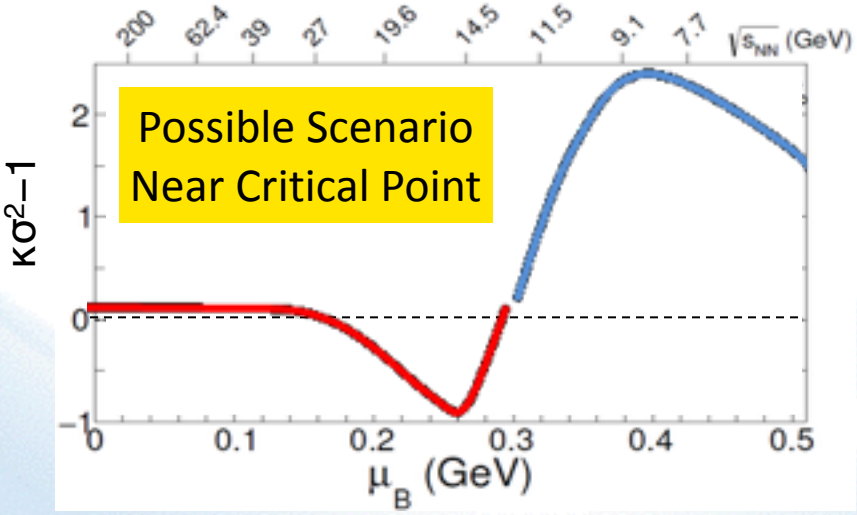
→ **Test scale evolution of transverse momentum dependent functions**
- → **Observable: compare magnitude of A_N for Drell-Yan and $W^{+/-}$**

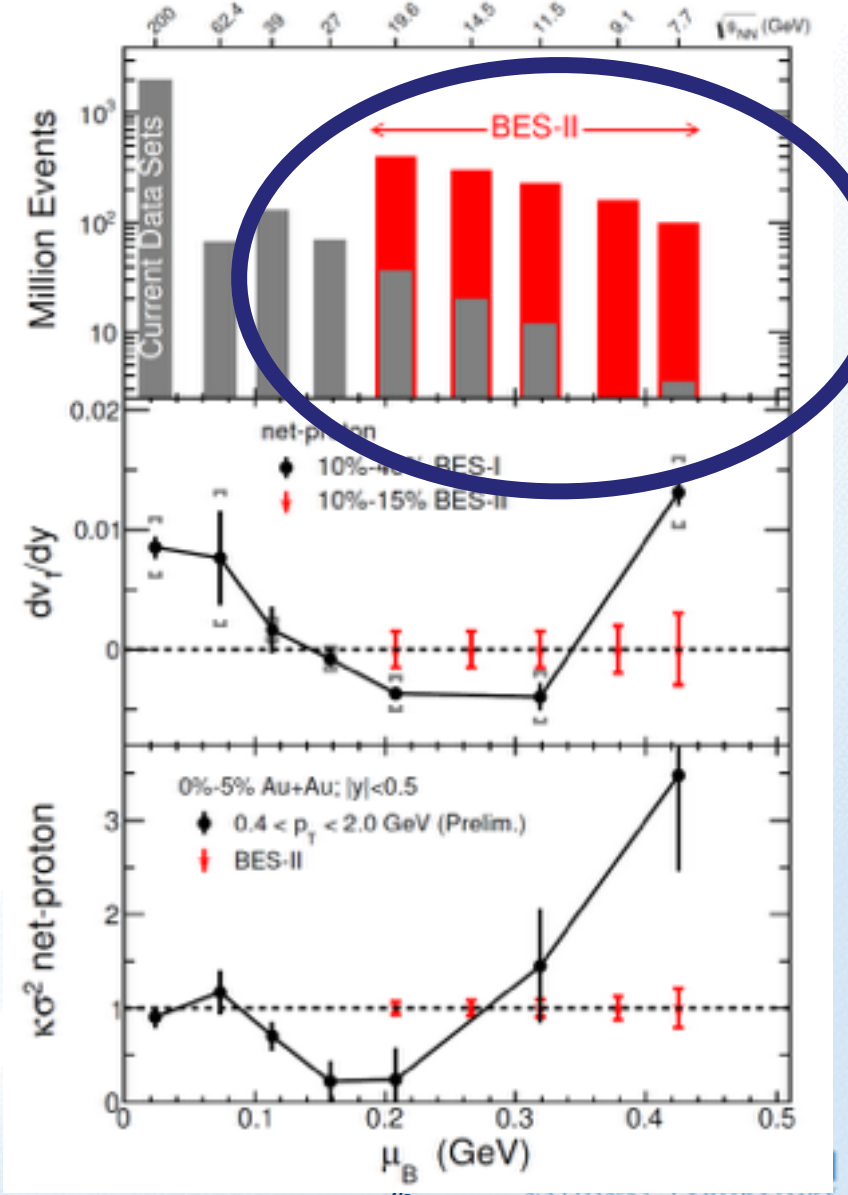
Scale: DY: $Q^2 \sim 16$ GeV^2 $W^{+/-}$: $Q^2 \sim 6400$ GeV^2

Toward critical fluctuations



Model independent structure of net baryon number kurtosis





The overarching scientific question:

How do asymptotically free quarks and gluons create the near-perfect liquidity of the QGP?

or

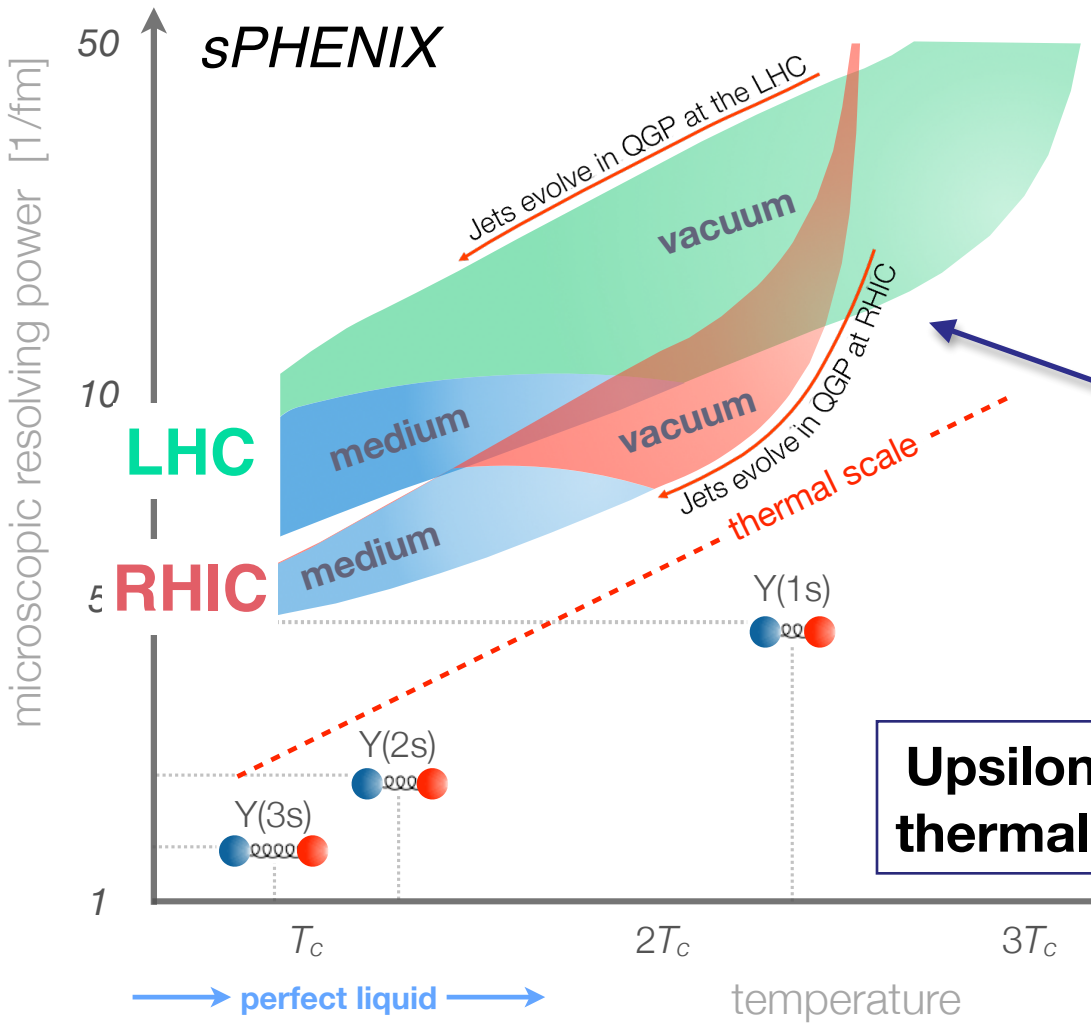
What degrees of freedom not manifest in the QCD Lagrangian produce the near-perfect liquidity of the QGP?

The (experimental) answer:

Deploy probes with a resolution that reaches well below the thermal ~ 1 fm scale of the bulk:

Jets & Upsilon states

Probing scales in the medium



How does the perfect fluidity of the QGP emerge from the asymptotically free theory of QCD?

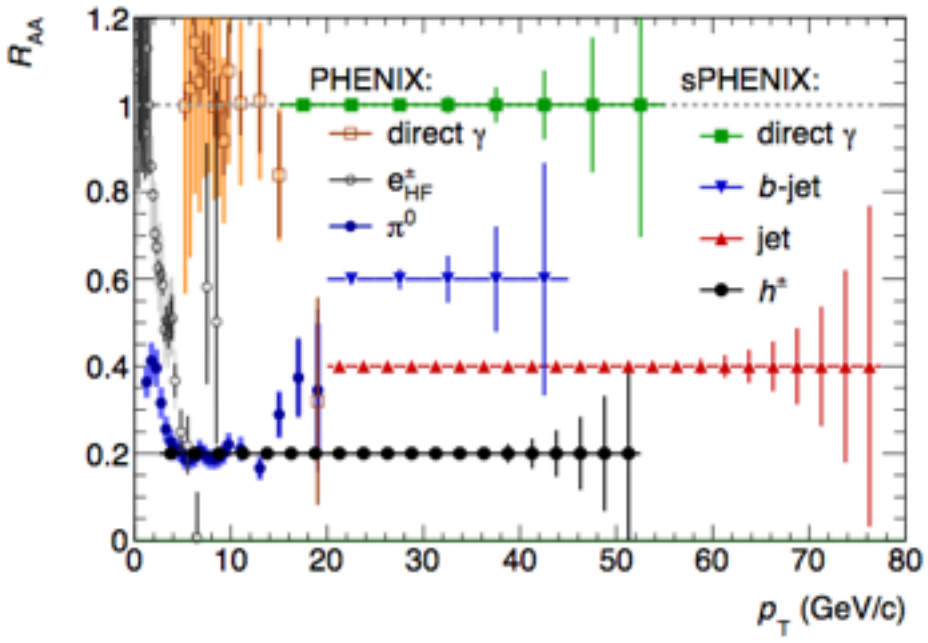
Jets probe sub-thermal length scales

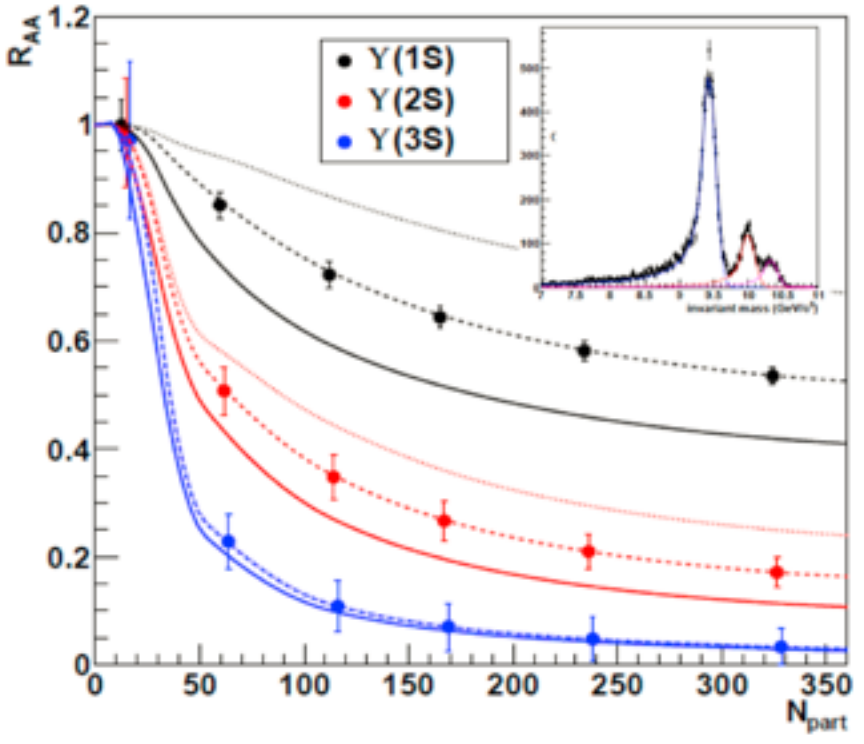
Upsilon states probe thermal length scales

Jets & Upsilon states

sPHENIX capabilities

Complete calorimetric jet spectroscopy





Completely resolved Upsilon spectroscopy

The Strategy

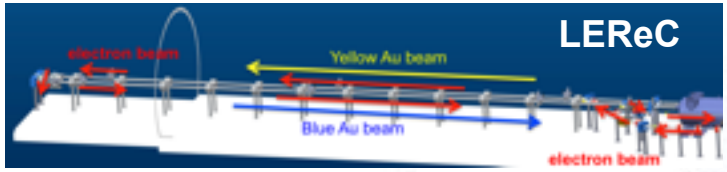
Completing the RHIC science mission

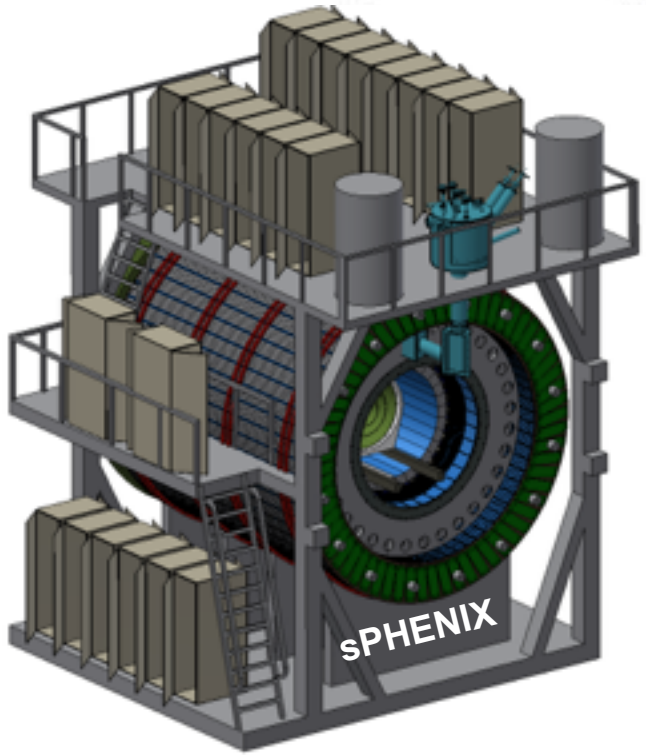
Status: RHIC-II configuration is complete

- Vertex detectors in STAR (HFT) and PHENIX
- Luminosity reaches 25x design luminosity

Plan: **Complete the RHIC mission** in 3 campaigns:

- **2014–17: Heavy flavor probes of the QGP using the micro-vertex detectors; Transverse spin physics**
- *2018: Install low energy e-cooling*
- **2019/20: High precision scan of the QCD phase diagram & search for critical point**
- *Install sPHENIX*
- **Probe QGP with precision measurements of jet quenching and Upsilon suppression**
- **Spin physics and initial conditions at forward rapidities with p+p and p+A collisions ?**
- *Transition to eRHIC*





RHIC remains a unique discovery facility

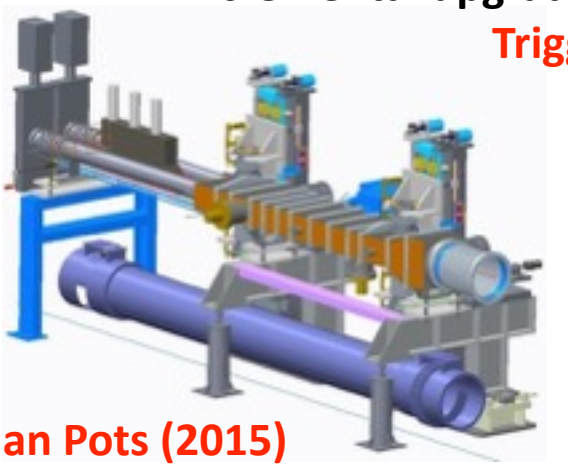
Proposed run schedule for RHIC

Years	Beam Species and	Science Goals	New Systems
2014	Au+Au at 15 GeV Au+Au at 200 GeV ^{3}He+Au at 200 GeV	Heavy flavor flow, energy loss, thermalization, etc. Quarkonium studies QCD critical point search	Electron lenses 56 MHz SRF STAR HFT STAR MTD
2015-16	p↑+p↑ at 200 GeV p↑+Au, p↑+Al at 200 GeV High statistics Au+Au d(p)+Au energy scan	Extract η/s(T) + constrain initial quantum fluctuations Complete heavy flavor studies Sphaleron tests Parton saturation tests	PHENIX MPC-EX STAR FMS preshower Roman Pots Coherent e-cooling test
2017	p↑+p↑ at 510 GeV Ru+Ru vs. Zr+Zr (A=96)	Transverse spin physics Sign change in Sivers function Isobar test of chiral magnetic effect	
2018	No Run		Low energy e-cooling install. STAR iTPC upgrade?
2019-20	Au+Au at 5-20 GeV (BES-2)	Search for QCD critical point and onset of deconfinement	Low energy e-cooling iTPC Event plane detector
2021-22	Au+Au at 200 GeV p↑+p↑, p↑+Au at 200 GeV	Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism Color screening for different quarkonia Forward spin & initial state physics	sPHENIX Forward upgrades ?
≥ 2023 ?	No Runs		Transition to eRHIC

STAR Upgrades and Performance Enhancements

Incremental upgrades/enhancements can have big impact!

Trigger/DAQ x2 throughput

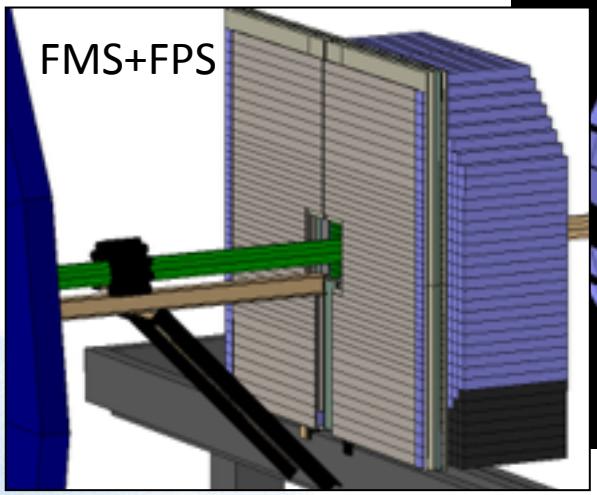


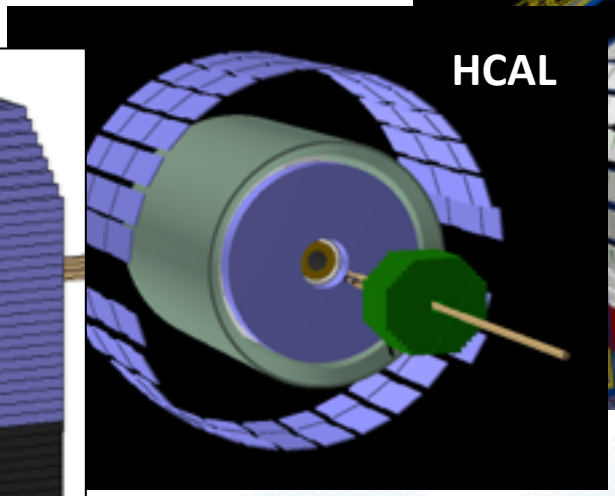
Roman Pots (2015)

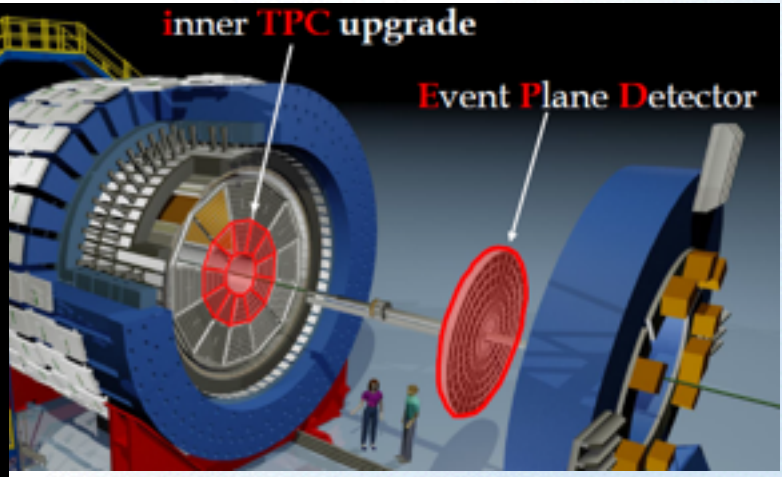
Tag diffractive protons

iTPC upgrade (2018)

Replace inner TPC Sectors
Extend rapidity coverage
Better particle ID
Low p_T coverage







FMS + pre-shower (2015) **Refurbished HCAL (2016--2020)**

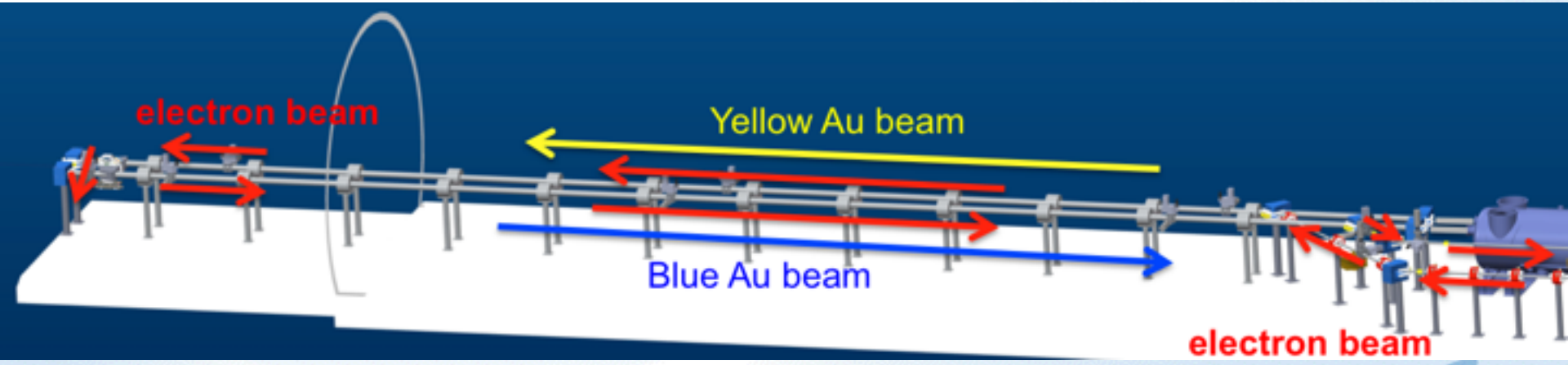
A_N photon, jets, Drell-Yan; ridge, fluctuation, spectators

Event Plane Detector (2018)

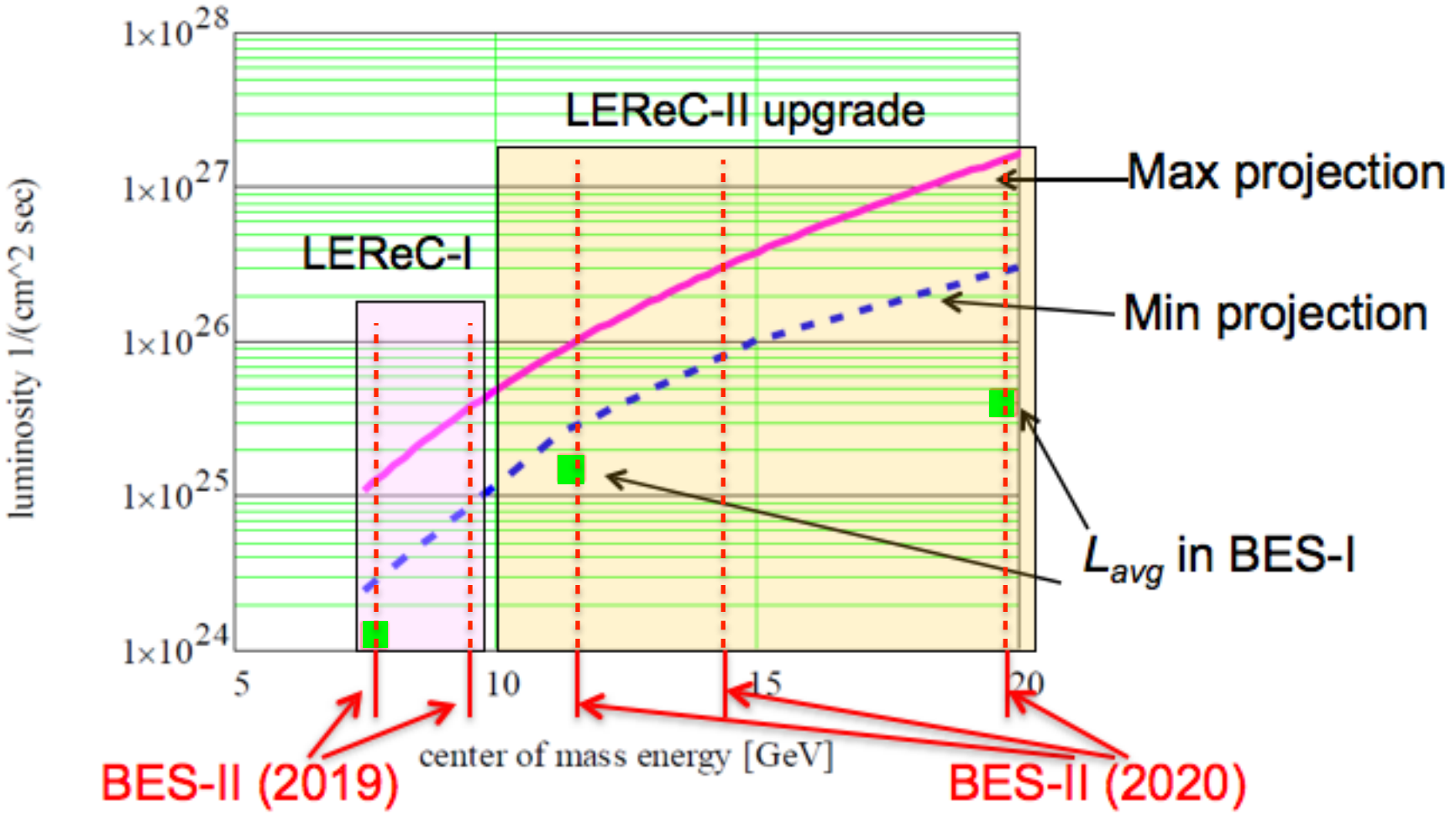
Improved Event Plane Resolution
Centrality definition
Improved trigger
Background rejection

Low Energy e-Cooling for Au+Au

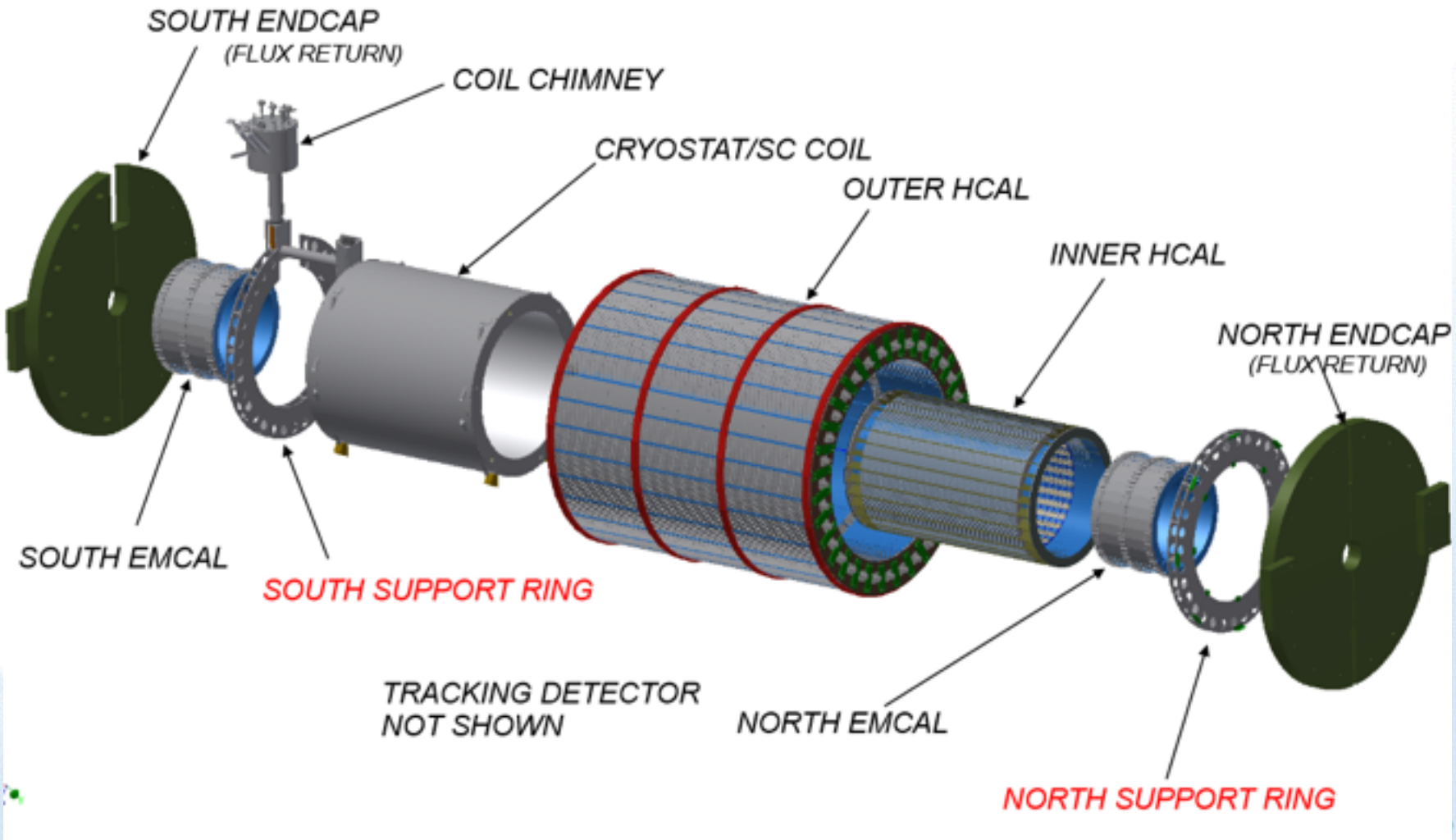
- Cooling of low energy heavy ion beams (3.8–10 GeV/n) with bunched electron beam increases luminosity by up factor 10
- Enables a QCD critical point search with a high statistics Beam Energy Scan
- Use either SRF electron gun or Cornell DC electron gun (for risk mitigation) and existing SRF cavity for cost effective implementation
- Stage 1: $\sqrt{s_{NN}} \leq 10$ GeV; stage 2: $\sqrt{s_{NN}} \leq 20$ GeV
- Cost: $8.3M (stage 1)
- Complete installation in 2018, use in low energy RHIC runs in 2019-20



BES-II luminosity

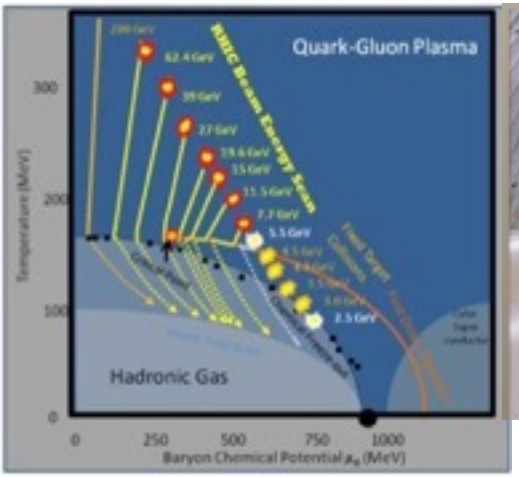


sPHENIX exploded view



BaBar magnet @ BNL

Collaboration Management



No hard barriers to membership in more than one RHIC project

- Collaboration rules do not prohibit "dual" membership
- STAR is open to admitting members of PHENIX interested, e.g., in the physics of the beam energy scan
  - Some groups have already switched, e.g. Stony Brook Chemistry
- STAR is open to membership in both STAR and "sPHENIX" construction
  - Several STAR member groups have expressed interest in new detector.

STAR has been charged to reevaluate by October 2015 its physics potential after the Beam Energy Scan Phase 2

sPHENIX Detector Workshop

June 16 Workshop at BNL:

A Large-Acceptance Jet and Upsilon Detector for RHIC

- Information for those interested in joining a new collaboration for a detector around the BaBar magnet
- Discussion of collaboration forming process (provisional IB formation, working groups, preparation of constitutive meeting in late summer)
- Connection to community interested in Day-1 detector for EIC
- Agenda at https://indico.bnl.gov/conferenceDisplay.py?confId=1191

New collaboration is open to all this who are interested. So far, >60 institutions (including many international ones) have declared interest. Provisional institutional board will meet soon to decide on path forward.

Budget issues

- As expected, we have used up RHIC Ops carry-over
  - Modest shortfall in RHIC Ops funds ay end of FY15 expected
  - Need to reprogram ~$1.5M AIP/CE FY15 funds to Operations
  - (>6% SLR increase, Run-14 electricity cost, BLIP, SMD labor)
- House FY16 budget would not allow for 22 week run
  - With PB and 22 week run: budgetary consequences
  - Minimal funding to run 15 weeks ($171.5M)
- RHIC experiments: Reduce staff by ~10 to match B/A.
- Committee looks into allocation of expt'l operation funds between Physics & C-AD
- Nuclear theory: remains un(der)funded by ~$1M
  - Stratmann not yet replaced (but promising candidate identified)
  - Strategic planning in progress (including role of RBRC)

Summary: Completing the RHIC mission

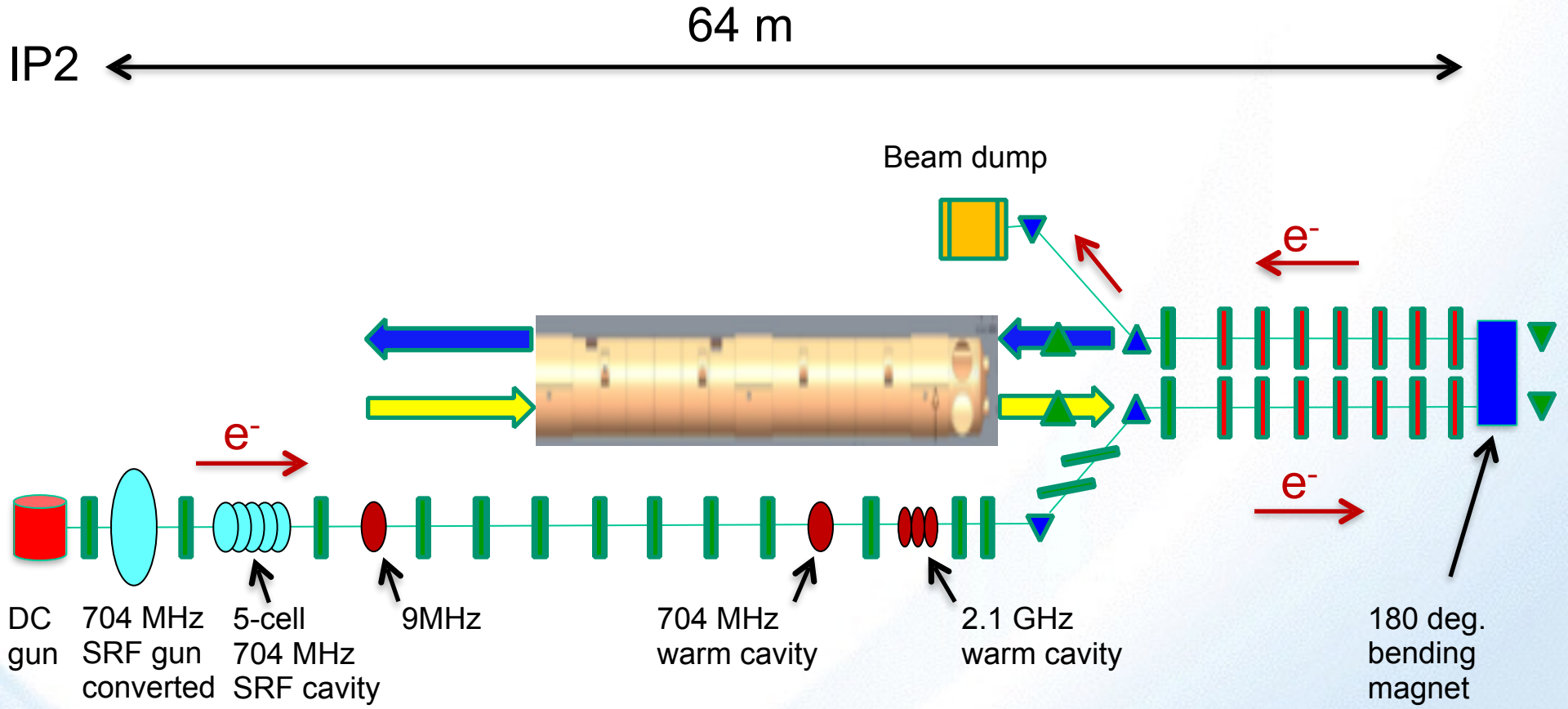
- **A unique forefront science program with continued discovery potential**
- **Quantify the transport properties of the QGP *near* T_c using heavy quarks as probes** (together with LHC)
- **Measure gluon and sea quark contributions to proton spin and explore transverse momentum-spin dynamics of QCD**
- **High statistics map of the QCD phase diagram, including search for a possible critical point**
- **Probe internal structure of the *most liquid* QGP using fully reconstructed jets and resolved Upsilon states as probes** (together with LHC)
- **Refine the physics program of an EIC with studies of *polarized* pp and pA collisions in forward kinematics?**
- **RHIC enabled R&D to retire major risks of eRHIC design**

Additional slides

What RHIC will deliver

- **Campaign 1 (2014-17):**
  - QCD equation of state at $\mu_B \approx 0$
  - Precision measurement of $\eta/s(T \approx T_c)$
  - Measurement of heavy quark diffusion constant $D_{c/b}$
  - Measurement of x-dependence of nuclear granularity
  - Origin of single spin asymmetries
  - Δg, flavor dependence of spin in the quark sea
- **Campaign 2 (2019-20):**
  - QCD equation of state at $\mu_B > 0$
  - Discovery of the QCD critical point, if within the accessible range
- **Campaign 3 (2021-22):**
  - Precision measurement of q^($T \approx T_c$) and e^($T \approx T_c$)
  - Determine length scale where the QGP becomes a liquid
  - Many additional insights we can't even anticipate yet !

LEReC-I (1.6-2MeV): Gun to dump
SRF gun used as a booster cavity



LEReC-II (energy upgrade to 5 MeV): ERL mode of operation